ON THE FISHERY, BIOLOGY AND THE HATCHERY TECHNOLOGY OF THE PORTUNID CRAB *PORTUNUS PELAGICUS*

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BY

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DECLARATION

I hereby declare that this Thesis entitled "On the fishery, biology and the hatchery technology of the portunid crab Portunus pelagicus" is based on my own research and has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

Cochin 682 014

May 2001

(Josileen Jose)

CERTIFICATE

This is to certify that the Thesis entitled " On the fishery, biology and the hatchery technology of the portunid crab Portunus pelagicus" is the bonafide record of the work carried out by Smt. Josileen Jose under my guidance and supervision and that no part thereof has been presented for the award of any other Degree or Diploma.

Cochin 682 014

May 2001.

(Dr. N. Gopinatha Menon)

Senior Scientist,

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Supervising Teacher

Dedicated to

The Almighty God

The Creator and Sustainer of the Universe

In loving memory of my

Beloved father Mr. C. L. Jose

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PREFACE

PREFACE

Crabs occupy a very important position in the commercial crustacean fisheries on account of their export potential and high nutritive value. The blue swimmer crab *Portunus pelagicus* (Linnaeus) supports a good fishery in the Palk Bay and the Gulf of Mannar and forms the major crab species caught in trawl nets. As this species gains greater importance in terms of availability, abundance and local/ export demand it is felt necessary to conduct detailed investigation on its fishery, biology and hatchery technology with the ultimate objective to formulate management strategies for sustainable exploitation/conservation and farming. This study is all the more important currently due to a continually declining capture fisheries of target groups, which consequently necessitated input controls in the capture sector, slowly leading to under employment in the traditional sector. The results of this study would open up new avenues for domestication of crabs thus leading to generation of employment potentials to the fishing communities and marginal farmers, besides enhancing the coastal production.

Although shrimp culture has been widely accepted as one of the major attractions of aquaculturists, in recent years they encountered heavy loss due to disease out breaks in several shrimp farms of Asian countries. Therefore, in the above context it has become necessary to diversify the culture operations to include other biologically and economically viable crustaceans. The blue swimmer crab is found to be one of the suitable species for mariculture.

The non- availability of crab seed is the main constraint in crab culture at present. The farmers are completely dependent on the natural sources for seed and juvenile crabs. Several workers have demonstrated larval rearing and seed production of *Scylla* spp. Large-scale seed production of *P. pelagicus* have not been undertaken in our country except for a few larval rearing trials by Prasad and Tampi (1953) and Raman *et al.* (1987). Hence the present study is an attempt to standardise and popularise a technology for the hatchery production of seed of *P. pelagicus* with a view to overcome the shortage of crab juveniles from the wild for farming and also to

replenish the depleting wild stock by sea ranching, which would enhance wild harvest of crab from the region.

The thesis is presented in five chapters.

Chapter I deals with a general introduction covering review of works on crabs with special reference to *Portunus* spp.

Chapter II deals with the capture fishery, which describe the craft and gear, landings, catch per unit effort, seasonal fluctuation, catch composition and age and growth in natural stocks.

Chapter III explains the biological aspects of *P. pelagicus* such as morphometric characters, length-weight relationships, sex ratio, male and female reproductive systems, maturity, fecundity, parasitization and food and feeding.

Chapter IV describes reproduction, larval development, the pattern of moulting and growth, behavioural habits, maturation, incubation and spawning of the species under laboratory conditions.

Chapter V deals with hatchery production of seed, hatchery operations and management, design and layout of the hatchery.

Materials and Methods for the study are given in respective chapters and wherever required statistical methods are applied to test the significance of relations. Summary of important findings of the study and references are included at the end of the thesis.

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CHAPTER 1

CHAPTER I
INTRODUCTION

Crabs belonging to more than 4500 extant species of decapod crustaceans are included in the infraorder Brachyura. The brachyura show extreme versatility in distribution. They are found in all climates, and in terrestrial, semi terrestrial and from the shore to deep sea, in marine, brackish as well as freshwater environments. Although earlier surveys have recorded above 640 species of crabs from Indian waters, only eight species are commonly referred to as 'edible crabs' inhabiting the coastal waters and adjoining brackishwater environment and support localised and sustenance fishery to some extent. Crabs are members of Crustacea, a class of invertebrate phylum Arthropoda that includes the animals with jointed legs and a hardened outer covering or exoskeleton. Crab belong to the order Decapoda a name which refers to this fact that the members of this order have 5 pairs of legs. The true crabs are placed in the suborder Brachyura an appropriate name for this group, as their shortened flap-like abdomen or tail is folded under the body (Rees, 1963). The presently studied crab *Portunus (Portunus) pelagicus,* is a marine species belongs to the family Portunidae and subfamily Portuninae. Although the latest nomenclature of the crab is *Portunus (Portunus) pelagicus* (Linnaeus), for the sake of brevity, '*Portunus pelagicus*' is used throughout the text.

In the Indian Ocean, the crab fauna of Portunidae family is included under sub families, Podophthalmidae (Borradaile), Catoptrinae (Sakai), Portuninae (Rafinesque), Caphyrinae (Alcock), Carcininae (Macleay) and Polybiinae (Ortmann). Most of the edible crabs caught from marine and brackishwater environments belong to the sub family Portuninae. In the seas around India, five genera of Portuninae have been reported by various authors. They are *Scylla, Portunus*, *Charybdis, Lupocyclus* and *Thalamita.* Among them the first three genera contribute to the commercial crab fishery.

The richness, variety and fishery of marine crabs of Indian seas have been investigated by many workers over the past 100 years. Among them the notable

works are of Alcock (1895,1896,1898-1900), de Man (1908), Kemp (1915,1919a,b), Chopra (1931, 1939), Prasad and Tampi (1951,1953), Menon (1952), Jones and Sujansingani (1952), Chhapgar (1957, 1962), Sankarankutty (1961a, b,1965), George and Nayak (1961), Ramamurthy (1972), Prasad and Nair (1973), Rao *et al.* (1973), Dhawan *et al.* (1976) and Kurup *et al.* (1990).

In seafood export, among crustaceans, crabs occupy third position, first and second being shrimps and lobsters based on their external market demand. Even though, its present status is not comparable to that of shrimps, crabs support a sustenance fishery of appreciable importance. Although the contribution of crabs to all India marine fish catch was low in the early sixties amounting to only 4000 tonnes, it increased steadily to 25,000 tonnes by nineties due to the expansion of trawl fisheries (Sukumaran and Neelakantan, 1996a). But, still the crab fishery of India has not commercially developed as in other countries. According to Suseelan (1996) an average of about 25,000 t of crabs are exploited annually from the marine sector, of which more than 50% being landed in the states of Gujarat and Tamil Nadu.

Geographical distribution of *P.pelagicus* ranges from Red sea, Mediterranean, East coast of Africa, Persian Gulf, Pakistan, India, Sri Lanka, Mergui Archipelago, Singapore and Philippines to Australia, New Zealand, Tahiti, China and Japan.

Pioneer works on crab are of Henderson (1893), Alcock (1895,1896,1898-1900), Laurie (1906), Kemp (1919a,b), Gravely (1927), Chopra (1931) and Blass (1935). Stephenson and Campbell (1959) described 13 species of the genus *Portunus* from Australia, including one new species and five new records. Stephenson (1961) described eight species of the genus *Portunus* from Australian waters. Two new genera and fourteen new species of Japanese crabs were reported by Sakai (1963). Chhapgar (1957) described marine crabs of erstwhile Bombay State. Sankarankutty (1961a,b) listed five species of *Portunus* from Andaman-Nicobar islands and a single species from Laccadive Archipelago. The distribution of *Portunus affinis* in the eastern tropical pacific was given by Jerde (1967). Eighty eight species of decapod brachyura are investigated from the Indian coast of Gulf of Mannar and Palk Bay which include five species of *Portunus* (Sankarankutty, 1965). Earlier reports from Andaman and Nicobar islands were by Heller (1868) who recorded 27 species of

crabs belonging to the three families Portunidae, Ocypodidate and Grapsidae and Alcock (1899a,b & 1900) described 35 species of portunids. Earlier investigations on the brachyura fauna of Maldive and Laccadive Archipelagos were initiated by Alcock (1895, 1896, 1898, 1899a,b and 1900) and Borradaile (1903 and 1906). Chandy (1973) reported new records of brachyuran decapods from the Gulf of Kutch which include a single species, *P. pelagicus*.

A specialized fishery for *P. pelagicus* exists in Australia, which is developed from a highly seasonal non-target fishery with its own specific scheme of management regulations. *P. pelagicus* known as the 'blue swimmer crab' or 'blueys' in most Australian waters is referred to in Western Australia as the 'blue manna crab'. One of the detailed earlier report on blue swimming crab fishery in Australia was given by Thompson (1951). Mc Donald (1997) explains the South Australia's blue crab fishery, while the problems of inshore crab fishery in Western Australia is described by Campbell and Broderick (1997).

Many workers have reported the crab fishery of Indian seas. General information is available from the works of Rai (1933), Chopra (1936, 1939), George and Rao (1967), Rao *et al.* (1973), Prasad and Nair (1973). Crab fishery of different regions along west coast was studied by Menon (1952), George and Nayak (1961), Chhapgar (1962), Dhawan *et al.* (1976), Sukumaran et al. (1986), Sheeba (1988), Kurup *et al.* (1990), Sukumaran and Neelakantan (1996a) and Anil (1997). East coast crab fishery was dealt by Chidambaram and Raman (1944), Prasad and Tampi (1951), Jones and Sujansingani (1952), Chacko *et al.*(1953), Chacko and Palani (1955), Chacko (1957), Balasubramanian (1966), Thomas (1971), Mohanty (1975), Ameer Hamsa (1978b), Shanmugam and Bensam (1980), Lalitha Devi (1985) and Joel and Raj (1987).

General studies on crab reproduction and breeding in India are those of George (1963), Pillai and Nair (1968, 1971 and 1973a,b), Sri Krishnadas and Ramamurthy (1976), Simon and Sivadas (1979), Aruldhas *et al.* (1980), Varadharajan and Subramaniam (1980), Prasad and Neelakantan (1989) and Anilkumar *et al.* (1996). Notable international works in crab reproduction are the contributions from Brown and Jones (1949), Needham (1950), Doi (1967), Ryan (1967a,b), Genthe

(1969), Griffin (1969), Johnson (1980), Bauer (1986), Hooper (1986), Melville-Smith (1987), Hinsch (1988), Beninger *et al.* (1988), Tan-Fermin and Pudadera (1989), Diesel (1989), Lee and Yamazaki (1989), Sumpton (1990a,b), Attrill *et al.* (1991), Beninger *et al.* (1993), Koga *et al.* (1993), Sainte-Marie and Lovrich (1994), Emmerson (1994), Diesel and Horst (1995), Paul and Paul (1995), Norman (1996) and Nakasone and Murai (1998). Mating behaviour in crabs was studied by many researchers during different periods, Cheung (1966), Hartnoll (1969), Turoboyski (1973), Elner *et al.* (1987), Murai *et al.* (1995), Paul and Paul (1996), Knuckey (1996) and Gardner *et al.* (1998).

It was the work of Drach (1936, 1939) who initially demonstrated the moulting process as not to be a discrete independent occurrence in the life of crustaceans but rather as a process encompassing approximately 70% of the duration between the successive moults. He divided the moult cycle into four basic periods, 5 major stages and several substages. Feeding metabolism and reproduction are affected directly and indirectly by periodic replacement of the integument. Subsequent publications have confirmed this hypothesis for a large number of crustaceans (Carlisle and Knowles 1959; Passano 1960).

Hiatt (1948) has described a growth model for the lined shore crab *Pachygrapsus crassipes*. Growth and age determination of the Pacific edible crab *Cancer magister* done by Butler (1961). Kurata (1962) has explained different factors determining the growth in crustacea. Effects of temperature on growth and metabolic rate of juvenile blue crabs , *Callinectes sapidus* has been explained by Leffler (1972) through laboratory experiments. Studies by Bennett (1974) gives details of moulting and growth in *Cancer pagurus* L. Mauchline (1976) provides information about growth pattern in class Crustacea. In their experiment Anderson and Ford (1976) reared *Cancer anthony* to study its growth and explains the sexual maturity stages and Carroll (1982) studied the growth in *Cancer antennarius*. Growth differences in *Sesarma cinereum* and *S. reticulatam* has been reported by Sieple and Salmon (1987) and a growth model for the deep sea Red crab-*Geryon maritae* off south west Africa was given by Melville-Smith (1989). The spatial and temporal patterns of moulting in *Callinectes sapidus* is detailed by Ryer *et al.* (1990).

Effects of autotomy, temperature, feeding and several other similar factors on growth and moulting has been reported by several authors: Smith (1990), Kondzela and Shirley (1993), Hancock and Edwards (1967), Turoboyski (1973), De Fur *et al.* (1988), De Fur (1990), Ryer *et al.* (1990), Lachaise *et al.* (1993), Hoenig *et al.* (1994), Shafer *et al.* (1994), Paul and Paul (1995). In his study Menon (1952) details the laboratory growth pattern of *P. pelagicus* for a few postlarval stages. The relative growth of different body parts in male and female *Portunus pelagicus* is given by Prasad and Tampi (1954). Ameer Hamsa (1978a) records the growth of *P. pelagicus* in the laboratory for few juvenile stages. Works of Prasad and Neelakantan (1989) explains the secondary sexual characteristics in association with the maturity moulting in mud crab *Scylla serrata*. Growth and maturity in *Portunus* spp. is given by Jacob *et al.* (1990), Reeby *et al.* (1990a) and Sukumaran and Neelakantan (1996a).

Morphometric measurements have wide applications in fishery biological investigations. Morphometric analysis of the crab *Portunus* is given by Stephenson (1966). Morphometric and morphological criteria are established for the determination of two sexually mature instars in females and three in males of *Portunus sanguinolentus*, a commercially important species of the Indo-west Pacific fauna (Ryan, 1967c). Relative carapace and chela proportions in some ocypodid crabs (Brachyura) were studied by Barnes (1968). In her experiments Lalitha Devi (1985) has described the morphometry in *Scylla serrata*, *Portunus pelagicus* and *P. sanguinolentus*. Observations of Suhalya and Rashan (1986) give information regarding the length and weight relationship of the crab, *Portunus magnum*. Chinnamma *et al.* (1986) has shown that morphometric measurements serve as an index for estimating quantum of meat in *S. serrata*. Morphometry of the mud crab *Scylla serrata* is described by Prasad and Neelakantan (1988 a). Studies on morphometric growth of the crab *Charybdis natator*, in Moreton Bay, Australia is explained by Sumpton (1990, b). A similar study on *Callinectes ornatus* was conducted by Haefner (1990). Chatterji *et al.* (1994) have studied the length- weight relationship of the Indian horse shoe crab *Tachypleus gigas*. Nandi *et al.* (1996) detailed the biometrics of the mud crab, *Scylla serrata* from Sunderban area of West Bengal. Length-weight relationship in *P. pelagicus* and *P. sanguinolentus* has been

studied by Sukumaran and Neelakantan (1997b). Sexual dichromatism in three species of Portunid crabs is given by Hopkins (1963).

Fecundity is an index of reproductive capacity and is designated in terms of the number of eggs produced by the organism. Fecundity among decapods varies widely within families and genera. In his study, Chhapgar (1956) has discussed about the reproductive cycles and fecundity of the crabs of Bombay coast. Contributions by Pillai and Nair (1971), Joel and Raj (1980), Prasad and Neelakantan (1989), Reeby *et al.* (1990 b) and Sukumaran and Neelakantan (1997a) have substantiated the existing knowledge on fecundity of Indian portunid crabs. Fecundity of *Ovalipes punctatus* (Du Preeze and Mc Lachlan, 1984), *Geryon quinquedens* (Hines, 1988), *Callinectes sapidus* (Prager *et al.* 1990), *Chionoecetes opilio* (Sainte-Marie and Lovrich 1994), *Ranina ranina* L. (Kennelly and Watkins, 1994), *Platyxanthus patagonicus* (Carsen *et al.*,1996) also have been worked out.

Hynes (1950) reviews the methods adopted in the analyses and studies of food and feeding of fishes. Most of the studies on food and feeding of other aquatic organisms are based on Hynes's study. Natarajan and Jhingran (1961) have discussed several methods of gut content analysis and describes the index of preponderance, its scope and construction. George (1965) described the anatomy and histology of different parts of the digestive system of the crab *P. sanguinolentus*. Studies have been made on the morphology of the mouth parts, structure of the gut and digestive physiology of mud crab *Scylla serrata* (Barker and Gibson, 1978). Jewett and Feder (1982) explains the food and feeding habits of king crab *Paralithodes camtschatica* near Kodaik island, Alaska. Feeding habits of the blue crab *Callinectes* spp have been studied by several workers; Tagatz (1968), Paul (1981), Laughlin (1982), Stoner and Buchanan (1990) and Rosas *et al.* (1994). Food of the tanner crab *Chionocetes bairdi* studied by Jewett and Feder (1983) and *Chionocetes opilio* by Wieczorek and Hooper (1995). Choy (1986) described the natural diet and feeding habits of the two species of the crab *Liocarcinus* and *Cancer* spp and *Ovalipes ocellatus* by Stehlik (1993). Natural diet and feeding habits of *Thalamita crenata* was investigated by Cannicci *et al.* (1996). There are several detailed reports on food and feeding habits of *Scylla serrata* Hill (1976, 1980), Williams (1978), Joel and Raj (1986) and Prasad

and Neelakantan (1988b). Investigations on diet and gut contents of *Portunus* spp are given by Hill (1980), Stephenson *et al.* (1982), Campbell (1984), Wassenberg and Hill (1987) and Sumpton and Smith (1990).

Investigations on physiological and toxicological aspects have been done by George (1968), Menon and Sivadas (1968), Nagabhushanam and Kulkarni (1976), Gribble and Reynolds (1993), Gribble (1994) and Chen and Chia (1996). George (1961a,b,c) described the anatomy of the crab *Neptunus sanguinolentus* in detail manner. Genetic differentiation in crab species has been studied by Felder and Staton (1994) and Anil (1997). Pillai and Nair (1973a) studied the fluctuations in the chemical constituents of gonads in *P. pelagicus*, while Badawi (1971) and Ameer Hamsa (1978c) investigated the chemical composition of the same crab. Lipid composition of the Queen crab *Chionoecetes opilio* was studied by Addison *et al.* (1972).

Many Indian workers studied the larval development of brachyuran crabs, either from the plankton net collections or by rearing berried females in the laboratory. Menon (1933,1937,1940), Prasad (1954) and George (1958) described the larval stages from the plankton collections. Naidu (1950, 1954, 1955, 1959, 1960 a,b, 1962, 1974) conducted several larval studies on many species of crabs. Prasad and Tampi (1953, 1957) explained the first zoea of *Neptunus pelagicus* and *Thalamita crenata* reared in the laboratory. Chhapgar (1956) described the zoeal stages of some portunid crabs. Krishnakumari and Rao (1974), Kakati and Sankolli (1975a,b,c), Srinivasagam and Natarajan (1976), Kakati (1977), Kakati and Nayak (1977), Kannupandi *et al.* (1980), Thomas (1984), Marichamy and Rajapackiam (1984, 1992), Raman *et al.* (1987), Josileen Jose *et al.* (1996) and Anil (1997) described the larval stages of different crabs species fully or partly through laboratory rearing experiments.

The brachyuran families which contain most species of current or probable future interest for food cultivation include the Canceridae, Portunidae, Majidae and Xanthidae. The Canceridae has many species of commercial interest, and a number of these have already been investigated with respect to larval rearing. *Cancer magister* of the west coast of the United States is a candidate species and the

important works on this species include Mir (1961), Poole (1966) and Reed (1969). Ally (1975) described the larval stages of *Cancer gracilis.* Anderson and Ford (1976) reared *C. anthonyi* and the larval development of *C. irroratus* was studied by Sastry (1977). Mass culture of the same species was undertaken by Charmantier-Daures and Charmantier (1991).

The Portunidae contains some of the most gastronomically and economically attractive crabs. For many years, Japanese have attempted to culture *Neptunus pelagicus* and *Portunus trituberculatus*. Yatsuzuka (1962) obtained 10% survival of larvae to the megalopal stage. Delsman and De Man (1925), Aikawa (1929), Prasad and Tampi (1953), Naidu (1955), Costlow and Bookhout (1960a), Shinkarenko (1979) and Raman *et al.* (1987) have reported larval stages of *Portunus* spp.

Scylla serrata is the other important portunid crab of the Indo-Pacific region and considerable emphasis on its larval development research is given. Arriola (1940) and Naidu (1955) did the pioneering work on larval development of *Scylla serrata*. A complete report on larval development of *Scylla serrata* is given by Ong (1964, 1966). Brick (1974) investigated the effect of water quality, antibiotics, phytoplankton and food on the survival and development of *Scylla* larvae. Hill (1974) has given the salinity tolerance of zoeae of *Scylla*. Other notable works include that of Haesman and Fielder (1983), Haesman *et al.* (1985), Marichamy and Rajapackiam (1984, 1992) and Anil (1997).

Thalamita crenata is another portunid crab in which many larval development studies are carried out. Prasad and Tampi (1953) has given the first zoeal description of this crab and Chhapgar (1956) collected first zoeal from plankton collection and is described. Greenwood and Fielder (1979), Thomas *et al.* (1980), Krishnan and Kannupandi (1990) and Godfred *et al.* (1995) have described the larval development of this species in detail.

The most important edible species of crab in the United States is *Callinectes sapidus* and its distribution there ranges from Cap Cod South to northern South America and is a rapidly growing species of high value. Because of its commercial significance, the blue crab *C. sapidus* and its different stages have been the subject of research for many years (Churchill, 1942; Hopkins, 1944, 1963; Sandoz and Hopkins,

1944; Sandoz and Rogers 1944; Costlow and Bookhout 1959, 1960b; Rust and Carlson 1960; Davis, 1965; Sulkin and Epifanio, 1975; Sulkin *et al*, 1976; Sulkin, 1978 and Millikin, 1978). Berrill (1982) studied the larval development of *Carcinus maenas* and Willems (1982) and Wolcott and Wolcott (1982) *Geocarcinus lateralis.* These studies have demonstrated that the larval stages of this species can be raised in the laboratory but with great difficulty and considerable expense.

Among the *Xanthidae*, several species have attracted interest and larval rearing experiments of few species have been particularly successful. Complete descriptions of all larval stages are available for *Neopanope texana* (Chamberlain, 1961), *Eurypanopeus depressus, Panopeus herbestii, P. africanus and Neopanope packardii*, (Costlow and Bookhout 1966; Costlow *et al.* 1962; Rodriguez and Paula 1993), *Rhithropanopeus harrisii* (Turoboyski, 1973; Christiansen and Costlow, 1975), *Pilumnopeus eucratoides* (Shirley *et al.* 1986), *Micropanope sculptipes* (Andryszak and Gore, 1981) and *Hexapanopeus augustifrons* (Costlow and Bookhout, 1966). In addition to the details based on laboratory rearing, a number of earlier workers have contributed information on larval development of the *Xanthidae* from studies on material obtained from plankton collections (Birge, 1883; Hyman, 1925).

The crabs which belong to family Grapsidae have also been studied by several workers. Costlow and Bookhout (1960a, 1962) describes larval stages of *Sesarma cinereum* and *S. reticulatum* , Costlow and Fagetti (1967) studied *Cyclograpsus cinereus*, Diaz and Ewald (1968) reported *Metasesarma rubripes, Sesarma guttatum* by Lago (1993) and Schuh and Diesel (1995a, b) describe *Sesarma miersii* and *S. curacaoense.*

Furota (1996a,b) describes the larval development of the spider crab *Pyromaia tuberculata.* The larval stages of frog crab *Ranina ranina*, has been studied by Minagawa and Murano (1993a,b) and Minagawa (1994). Sasaki and Mihara (1993) gives the larval descriptions for the hair crab *Erimacrus isenbeckii.* Also the works of Lebour (1945), Garth (1966), Hanson (1969), Christiansen and Yang (1976), Paul and Paul (1980), Sastry (1983), Barnwell (1986), Paula (1988), Mc

Laughlin *et al.* (1983) and Gherardi and Mc Laughlin (1995) dealt with larval development of different species of crabs.

Rearing methods for decapods were described by Costlow and Bookhout (1960b), Rice and Williamson (1970) and Sastry (1970). Ingle and Clark (1977) designed a laboratory module for rearing crab larvae.

CHAPTER II

CHAPTER II

FISHERY

INTRODUCTION

Crabs support a sustenance fishery of appreciable importance although its present status is not comparable with that of shrimps. Although the contribution of crabs to an annual total marine fish landings in India was low in the early sixties amounting to 4000 tonnes, it increased steadily to 25,000 tonnes by the nineties due to the expansion of trawl fisheries (Sukumaran and Neelakantan, 1996a). Still the crab fishery of India has not commercially developed as in other countries. During 1985-1993 contribution of crabs to total marine fish landings was 1.2% (Anon, 1995). Among the maritime states, Tamil Nadu dominated in crab landings, with a maximum recorded catch for the past several years.

The blue swimmer crab *Portunus pelagicus* (Linnaeus) is an important species in the marine sector which along with the 'three-spotted' crab *P. sanguinolentus* contribute upto 90% of the crab landings in India. Though *P. pelagicus* is fished in all maritime states of India, a good fishery exists only in Tamil Nadu and Karnataka. Along the east coast, bulk of the catches is landed from Gulf of Mannar and Palk Bay. Good landings are recorded from Nagapattinam and Pondicherry in Tamil Nadu (Rao *et al.* 1973).

Crabs are mainly caught in bottom trawl nets (targeted for shrimps and fishes), as a by-catch, operated in deeper water upto 50 metres. The fishing ground is generally characterized by muddy bottom, rarely sandy or sand mixed with mud. Indigenous gears such as stake net, cast net, gill net, drag net, seine net, hoop net, hooked iron or steel rods, line with baits, shore seine, boat seine, crab traps are mostly restricted to shallow grounds upto 15 metres, (mostly 3-5 metres).

In most of the indigenous gears such as seine nets, shore seines, cast nets and bottom set gill nets operated for inshore fishes, crabs form an ancillary catch in good quantities. Some gears are used exclusively to catch crabs. The various contrivances such as hoop nets, lines, various types of iron or steel rods used around Bombay area and their operation methods have been described by Rai (1933) and Chhapgar (1962).

Gillnets with minor modifications locally known as *Aedi bale*, *Nandu valai* and *Peethu valai* are employed in Kanara, Gulf of Mannar and Palk Bay and Kakinada coasts respectively. Baited lines are also used to lure the crabs in Kakinada and in the lagoons and creeks of Sunderban area. *Portunus pelagicus* is also caught from numerous estuaries and brackishwater bodies along the coast with other species of crabs.

There is no detailed data on the blue crab landings in our country although many earlier workers reported its fishery. Chopra (1939) reported that crabs of the family Portunidae contribute the largest proportion of our food crabs and described the fishery of *Neptunus pelagicus* in Chilka lake, where it has accustomed itself to living in almost freshwater for at least some part of the year. Prasad and Tampi (1951) gave an account of the fishery and fishing methods for *Neptunus pelagicus* near Mandapam. Jones and Sujansingani (1952) also described the crab fishing of the Chilka lake and noted that *N. pelagicus* is the second important species. George and Nayak (1961) studied fishery of *N. pelagicus* from Mangalore coast. The crab fishery resources of India was given by Rao *et al.* (1973) and explained the fishery and fishing methods for *Portunus pelagicus.* Fishery of *P. pelagicus* in Zuari estuary was reported by Dhawan *et al.* (1976). Ameer Hamsa (1978b) has described fishery of swimming crab *P. pelagicus* from Gulf of Mannar and Palk Bay. Crab fishery of the Vembanad lake was studied by Kurup *et al.* (1990); *P. pelagicus* formed one of three important crab species exploited. In Karnataka, a good fishery for *P. pelagicus* exists along with *P. sanguinolentus* and details are given by Sukumaran and Neelakantan (1996c). Thompson (1951) gave a description of the sand crab (*N. pelagicus*) fishery in Moreton Bay, Australia.

MATERIALS AND METHODS

For the present study, *P. pelagicus* (Linnaeus) is the species studied in detail. Two ecologically different areas were selected for this study *i.e.* Palk Bay and Gulf of Mannar of the southeast coast of India. The study was carried out for a period of three years (1995-96, 1996-97 and 1997-98) at Mandapam Regional Centre of Central Marine Fisheries Research Institute, Mandapam Camp in Tamil Nadu.

After preliminary survey of crab fishery in Palk Bay and Gulf of Mannar, four important landing centres, Mandapam - Palk Bay, Mandapam - Gulf of Mannar, Devipattinam (Palk Bay) and Thoppukadu (Gulf of Mannar) were fixed as stations for regular sampling and monitoring the catch (Fig 2.1 and Plates 1 to 5).

Each station was visited once in every fortnight and observations were recorded for total units operated, total catch, catch composition and catch per unit effort and samples obtained. On each sampling day, total crab catch at every centre was recorded sex-wise and size-wise. Similarly, the details for non-sampling fishing days were collected from the merchant's diary for as many days as possible. The average daily crab landing was worked out from the data thus obtained and raised to the number of fishing days to assess the monthly total crab landings of the centre.

Mandapam, where the three sampling sites are located as seen in the figure is at the tapering end of the narrow strip of land projecting perpendicular to the south east coast with Palk Bay to the north and Gulf of Mannar to the south. The tidal amplitude here is about 0.75 m. During the south west monsoon, the coastal waters in the Gulf of Mannar become turbulent owing to strong winds. This condition generally continues upto August. The direction of water drift in this area is south north during April to August and the velocity in the Pamban Pass reaches at times 5-6 knots. During this period shore and near shore waters of the Palk Bay are calm. On the onset of the north east monsoon from September, the direction of the drift is reversed. During this period, comparatively calm conditions prevail in the Gulf of Mannar and the waters of the Palk Bay become turbulent.

Even upto a distance of about 16 km from the shore, the depth does not exceed 11-13 m, in the Palk Bay. In the Gulf of Mannar the area between coast and chain of islands are shallow as that of Palk Bay and beyond islands southward depth is much more. The inshore region of the Gulf of Mannar is full of fringe coral and reefs and corallar rocks with intervening areas of sand and mud. The south and west coasts of Palk Bay is mostly muddy with sea grass meadows with few coral areas near Mandapam. Dredge collections made in the Gulf of Mannar and Palk Bay reveal that the same species of flora exists in the bottom of both areas. The fauna associated with the flora in both habitats were also found to be fairly evenly

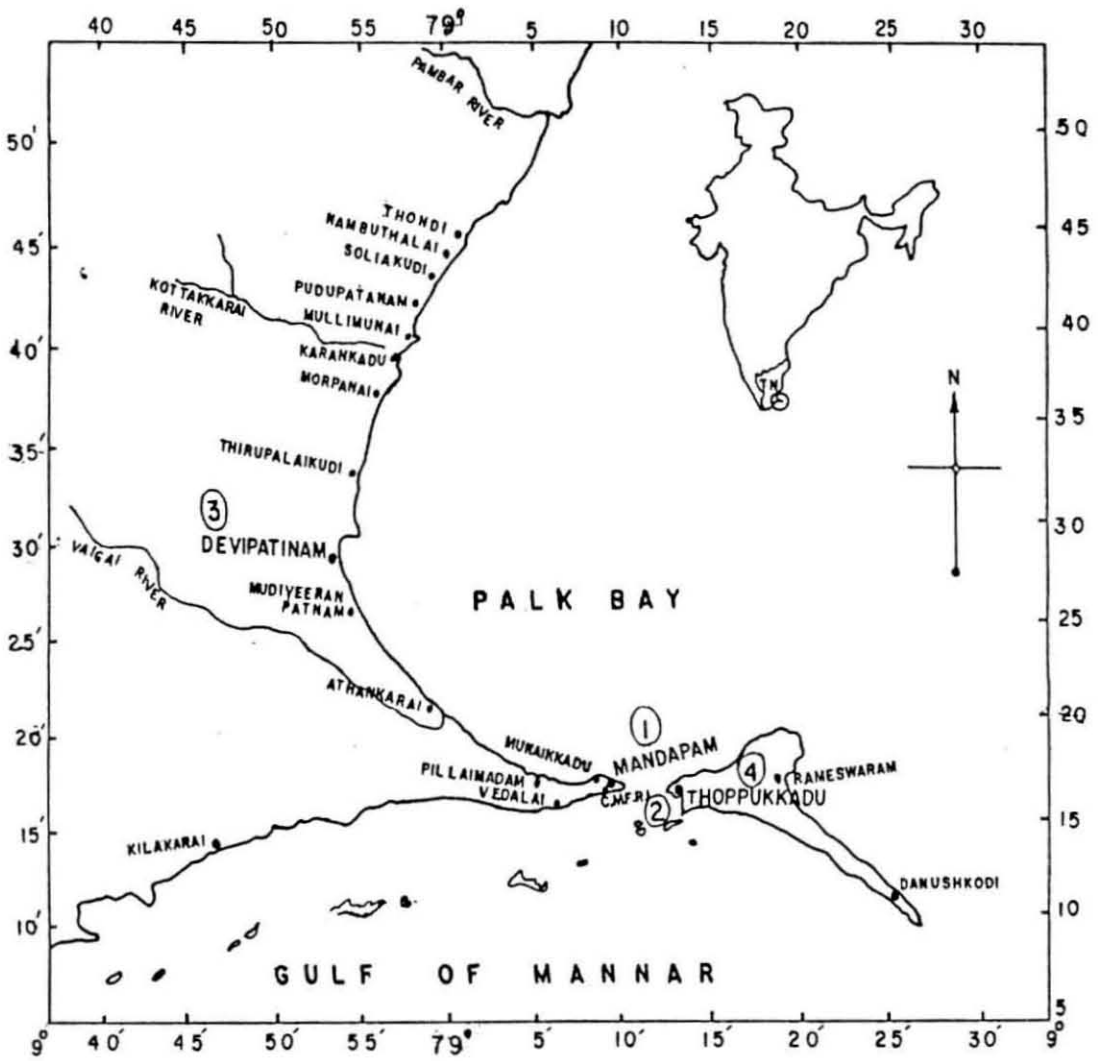


Fig. 2.1. The Map showing different stations of the study.

Plate 1

a

b

a&b - Landing Centre at Mandapam (Palk Bay)

Plate 2

a

b

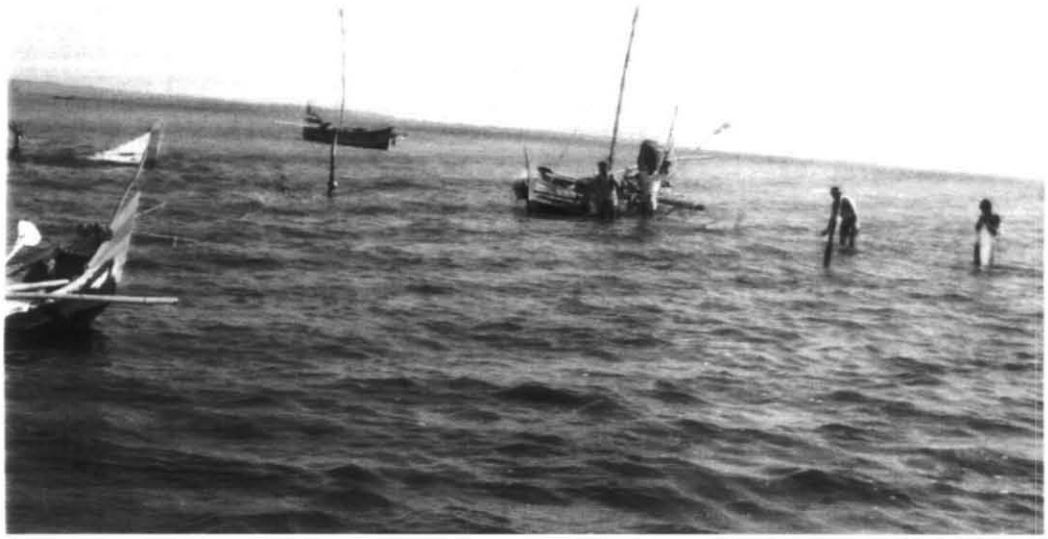
a&b - Landing Centre at Mandapam (Gulf of Mannar)

Plate 3

A catch of adult crabs of *P. pelagicus* at Mandapam (Palk Bay)

Plate4

a



b

a. Landing Centre at Devipattinam (Palk Bay)

b. Fishermen bringing the crab catch to the shore at Devipattinam

Plate 5

a

b

a. A fisherman showing a new *nanduvalai* at Devipattinam

b. A fisherman and his daughter with their *nanduvalai* at Thoppukkadu.

distributed (Pai, 1968). In the Gulf of Mannar, there is a chain of islands situated almost parallel to the coast at 5-10 km from the coast. These islands are mainly of coral origin and single. The waters between these islands and the mainland are more shallow than beyond.

Palk Bay and Gulf of Mannar although partly separated are not completely independent of each other and there is continuous mixing of water masses through the Pamban Pass (Chacko, 1950). Atmospheric temperature around this area fluctuates from 25°C to 31°C (Prasad 1957) with the maximum during April-May and minimum during December-January. Mandapam is a semiarid zone and the mean annual rainfall 920 mm, and precipitation is more or less confined to the months of October to December by northeast monsoon. Prasad (1957) reported that both in the Gulf of Mannar and Palk Bay the lowest salinity was recorded in January whereas, the maximum was recorded in June in Gulf of Mannar and September-October in Palk Bay. The productivity of Gulf of Mannar and Palk Bay has been estimated by Prasad (1958) and he has indicated that Palk Bay is more productive than the Gulf of Mannar. Almost same pattern of environmental conditions prevailed in Palk Bay and Gulf of Mannar during the recent past also (Gandhi, 1998).

Statistical analyses

During the fortnightly sampling, the male and female crabs were separated and they were classified into different size groups of 5 mm class intervals based on their carapace width. Their frequencies in various classes were worked out. These frequencies were weighed to the monthly catch estimate. This data was entered in the FiSAT computer programme for further analysis to estimate the growth parameters.

An integration of the data of different types of fishery was not attempted as there was marked variation in the size composition in catches. The data pertaining to trawl, which was the major single gear in the exploitation of crabs used for the analyses.

Probability of capture analysis

The sequence of analysis carried out as follows:

1. Estimate of $L\alpha$ by Powell-Wetherall method.

2. Correct length- frequencies for selection using the value 1.0 for the curvature parameter, K and the estimate of $L\infty$ obtained by stage-1.
3. Separate normally-distributed components by the Bhattacharya- method from the corrected length-frequency distribution.
4. Use the estimated mean lengths of the components in modal progression analysis to estimate the growth parameters K and $L\infty$.
5. Estimate Z using length-converted catch curve analysis with the newly-estimated growth parameters.

ELEFAN

ELEFAN- routine in FISAT was run to estimate the $L\infty$ and K and the following routines were carried out.

Curve fitting by eye

- Response surface analysis
- Scan of K values
- Automatic Search Routine

After running all these routines the parameter estimates with the highest R_n value was selected for both males and females.

The growth increment data obtained by linking of means in modal progression analysis was used to run the Gulland & Holt plot, Munro's and Fabens methods to find out the $L\infty$ and K values assuming that growth in carapace width follows Von Bertalanffy Growth Formula. From the parameters, estimate were selected based on comparison to the growth increments observed in the laboratory rearing experiments.

Yield-per recruit (Y/R)

Relative yield per recruitment Y/R was estimated by Beverton and Holt (1964) method.

Total mortality (Z), Natural mortality (M) and Fishing mortality (F):

The total instantaneous mortality coefficient (Z) was estimated from the length frequency based catch curve method. Since there is variation in growth parameters, the Z has been estimated sex wise.

The instantaneous natural mortality coefficient (M) was found out by the following methods:

1) The Rikhter and Efanov (1976) method employing the following formula ;

$M = 1.521 / (t_{m50})^{0.72} - 0.155$

where t_{m50} = age at which 50 % of the population mature.

2) The Pauly's (1980) method;

$\text{Log10 } M = 0.0066 - 0.279 \log_{10} L\alpha + 0.6543 \log_{10} K + 0.4634 \log_{10} T$

where 'T' is the mean annual environmental temperature (29^0 C is taken as the 'T' in the present study).

The instantaneous fishing mortality coefficient (F) was computed from the formula: $F = Z - M$

The exploitation rate (E) was computed from the formula : $E = F/Z$.

RESULTS

Craft and gear

At the Mandapam centre, bottom trawlers land *P. pelagicus* catch. This fishing is an year round process along Palk Bay while at Gulf of Mannar fishing activities are restricted for the season, October-March. The trawlers either operate both during day-night or night only and the fishing area was upto a maximum of 50 m, with normal fishing in grounds less than 25 m of depth. Among the trawlers, majority (70%) are IB (inboard) type with overall length of the boat around 28-32' and horsepower varies between 48-58 and others are STB (Stern trawl boat) type with OAL ranges between 34-36' and HP between 68-88. The strength of the crew is between 4-5 persons per boat.

At Devipattinam and Thoppukadu, crab fishery is exclusively by a traditional set gillnet known as *nanduvalai*. A group of 3-5 fishermen participate in fishing in a country boat locally known as *Vathai*. Overall length of the craft is 7-8 m and a single craft carries 15-25 nets depending on the number of crew. Each *nanduvalai* is about 200 m long and 1 m height. The netting is made of high-density nylon mono-filament with a stretched mesh of 80 mm. The head rope is a nylon with a 1.5 cm in thickness and small rubber floats are attached at intervals of about one

and a half feet. These rubber floats are about 6 cm in length and 1 cm in width, made of rubber waste of chappel industry. The foot rope is made of cotton which absorbs water and hence no sinkers are used. The above descriptions pertain only to crab nets used at Devipattinam; however few variations have been noticed in size of the net and other aspects of crab nets used in adjacent localities.

The nets are used in fleets, several of them tied end to end forming a long chain so that they cover a considerable area in the sea. Fishermen set sail for fishing during evening hours, carrying the fleet of these nets. One person rudders the *Vallam*, while others lay the net at a depth of 4-5 metres and about 0.5 to 1 km from the shore, always parallel to the coastal line. Actual fishing period is three hours only *i.e.* in the first hour they spread the net, next one hour they will wait for entangling crabs and third hour will be spent for hauling the nets with entangled crabs. The crabs which try to cross the long chain of net get themselves further entangled in the meshes and cling to the nets. The entangled crabs are removed from the nets with much care and skill without breaking its appendages. These crabs are either sold in the local market or to the wholesale merchants.

Total catch

Mandapam : For the 1995-98 period, the total estimated catch of *P. pelagicus* at Mandapam (Palk Bay) was 502.384 t with an average CPUE (catch per unit effort) and CPH (catch per hour) of 4.2 kg and 0.324 kg respectively. The annual total crab catch was found declining from 1995-96 to 1997-98. The details are given in the following table.

Year	Total units	Total fishing hours	Total catch (t)	CPH (kg)	CPUE (kg)	% of crab in Total landings
1995-96	41110	535290	197.243	0.368	4.8	3.3
1996-97	41582	540697	181.755	0.330	4.4	3.5
1997-98	36344	475730	123.386	0.259	3.4	2.6
Total	119036	1551717	502.384	0.324	4.2	3.2

At Gulf of Mannar side total landings for the 1995-98 period was 30.686 tons with a CPUE 1.23 kg. In the overall catch *P. pelagicus* formed 4.4%. The catches

were fluctuating and an average catch of 10 t/year was recorded. The details are given in the following table.

Year	Total units	Total fishing hours	Total catch (t)	CPUE (kg)	CPH (kg)	% of crab in total landings
1995-96	8781	84340	10.727	1.22	0.120	5.1
1996-97	7166	63473	9.844	1.40	0.131	4.7
1997-98	9252	87490	10.113	1.10	0.130	3.6
Total	25199	235303	30.684	1.23	0.130	4.4

In all the years maximum catch was recorded during the month of June at Palk Bay. At Gulf of Mannar during 1995-96, maximum was recorded during March and in following years during December. For the three years month wise catch details are given in the figures 2.2 to 2.7.

Devipattinam : At Devipattinam, total estimated catch for the three years was 108.167 t with a CPUE of 13.3 kg and CPH 4.4 kg. Yearly split up of effort, fishing hours, total catch and catch rates are given below.

Year	Total units	Total fishing hours	Total catch (t)	CPH (kg)	CPUE (kg)
1995-96	3937	11811	30.330	2.6	7.7
1996-97	2686	8056	42.615	5.3	15.9
1997-98	1508	4524	35.222	7.8	23.4
Total	8131	24391	108.167	4.4	13.3

The maximum catch was recorded during September in the first year, March in the second year and June in the last year. The month wise catch details for the three years are given in the figures 2.8 to 2.10.

TOTAL ESTIMATED CATCH AND EFFORT AT MANDAPAM (PALK BAY)

1995-96

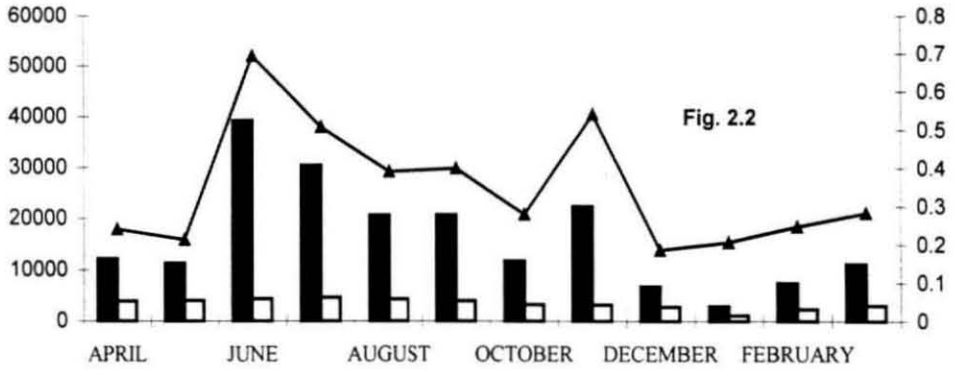


Fig. 2.2

1996 - 97

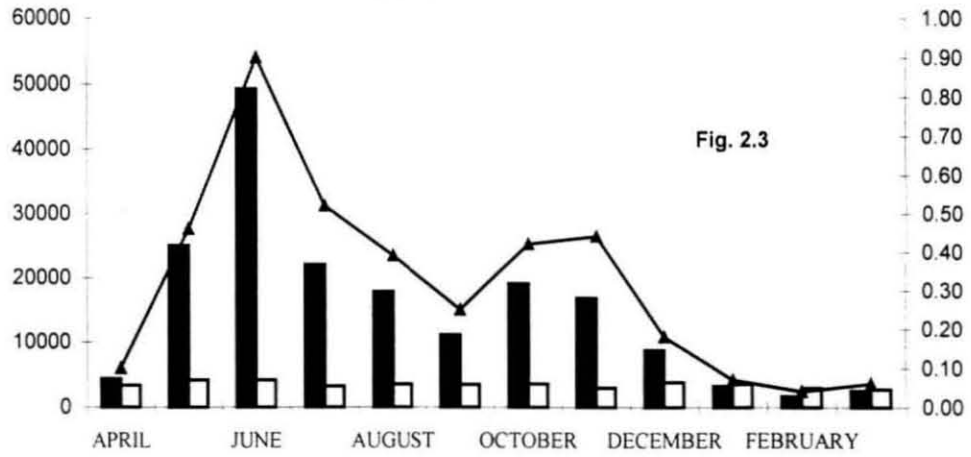


Fig. 2.3

1997 - 98

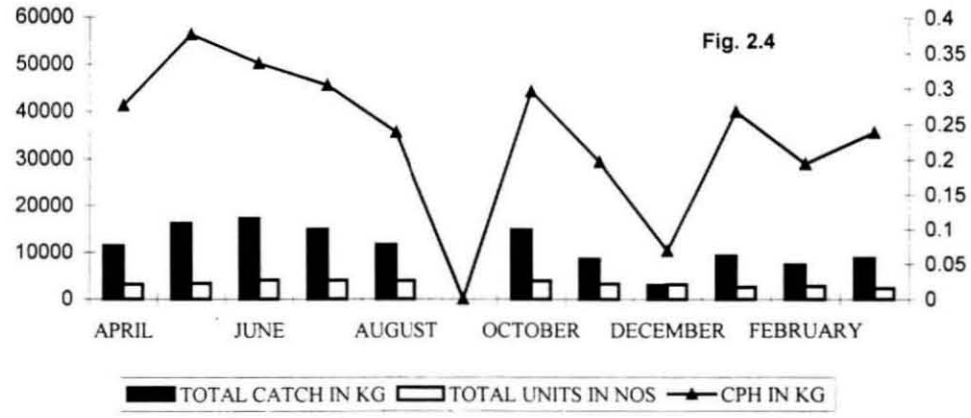
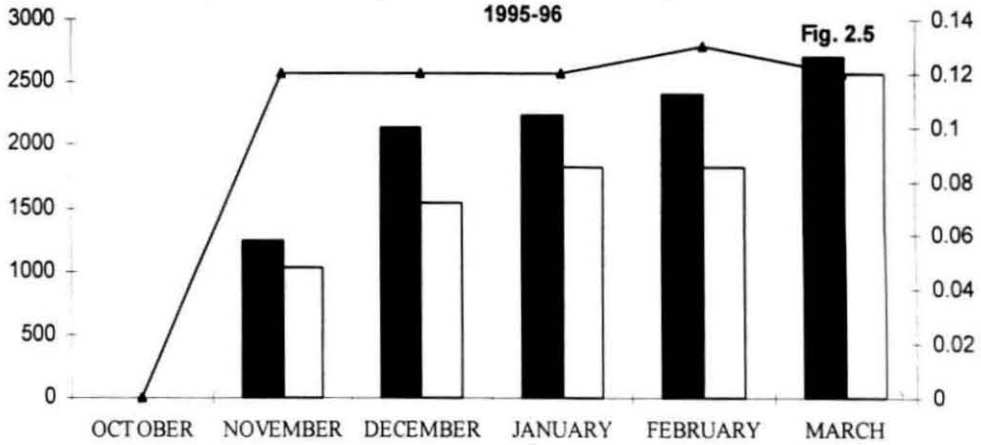


Fig. 2.4

TOTAL ESTIMATED CATCH AND EFFORT AT MANDAPAM (GULF OF MANNAR)

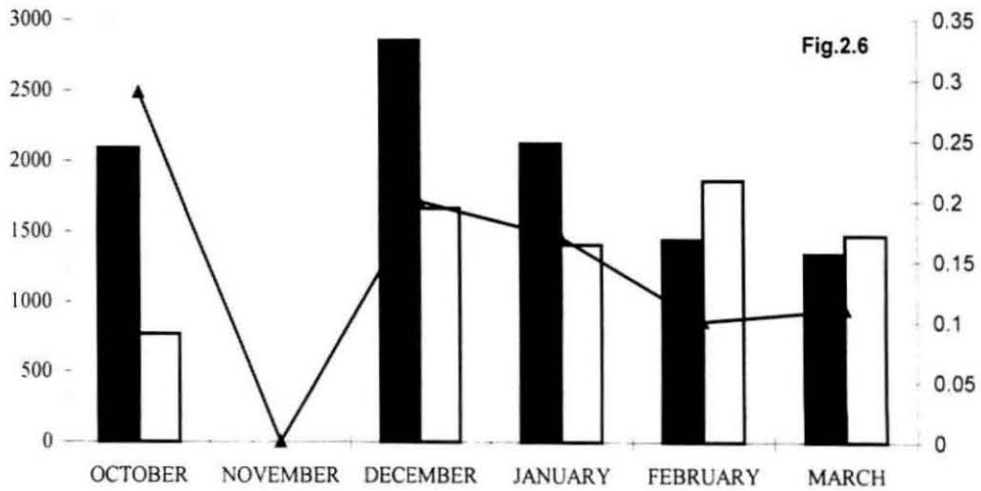
1995-96

Fig. 2.5



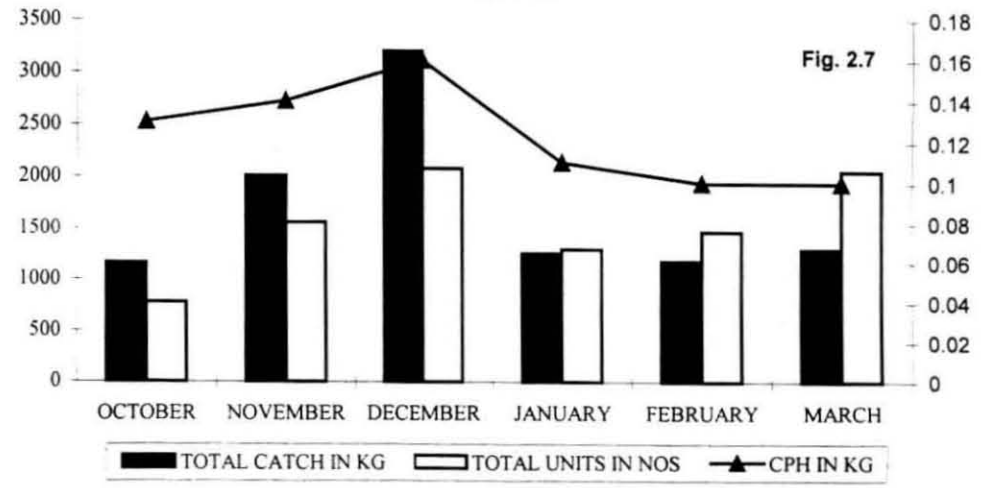
1996 - 97

Fig.2.6



1997 - 98

Fig. 2.7



TOTAL ESTIMATED CATCH AND EFFORT AT DEVIPATTINAM

1995 - 96

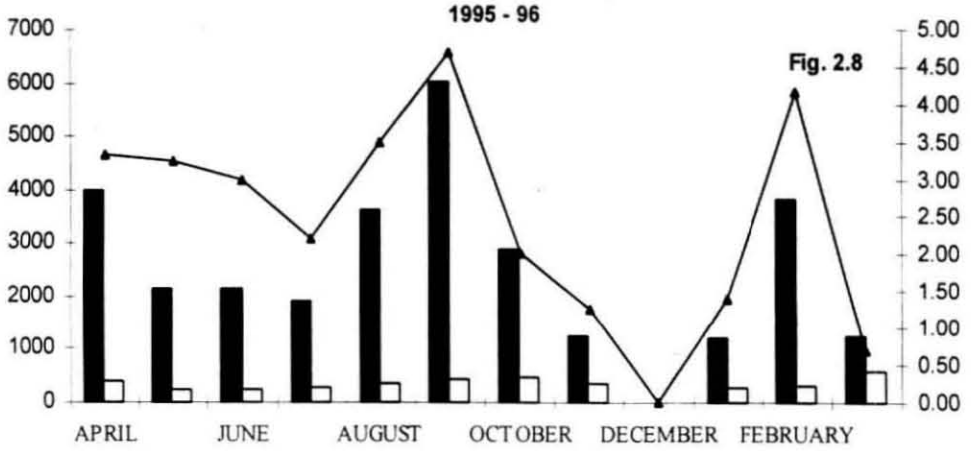


Fig. 2.8

1996 - 97

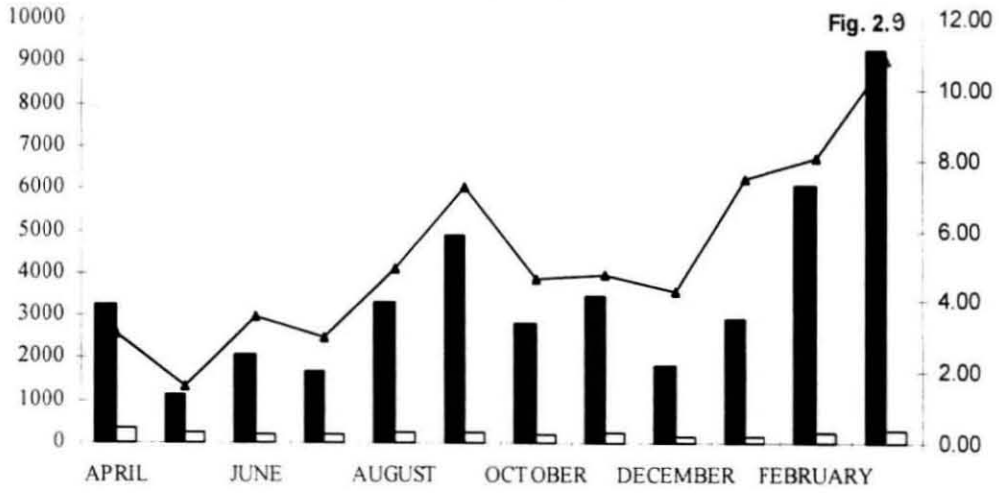


Fig. 2.9

1997 - 98

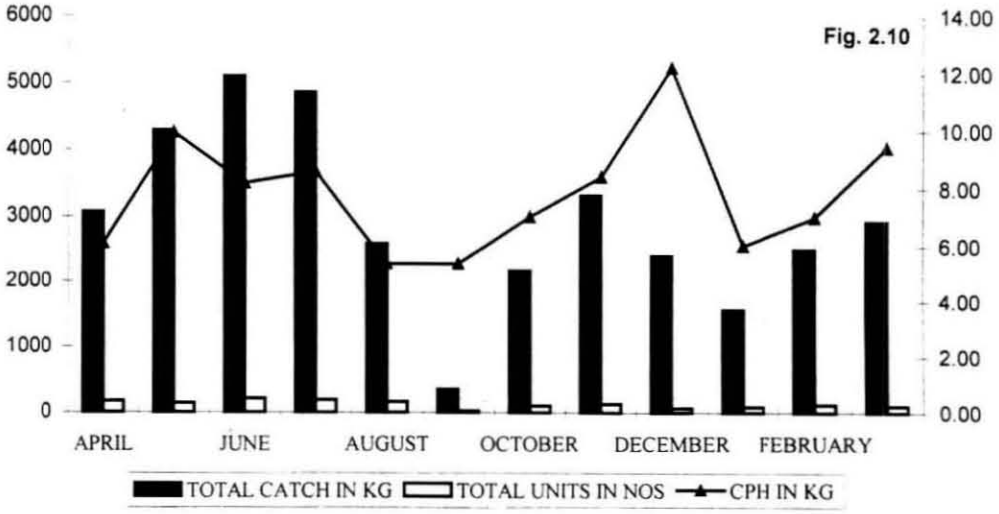


Fig. 2.10

Thoppukadu: At Thoppukadu the total estimated catch for three years was 17.204 t with an average annual production of 5.43 t. CPUE and CPH were 2.01 kg and 0.67 kg respectively. Among the total catch *P. pelagicus* contributed 62.32% and rest by *Scylla* spp. The details of *P. pelagicus* catch are given in the following table.

Year	Total units	Total hours	Total catch (kg)	CPUE (kg)	CPH (kg)	% of *P. pelagicus* in overall crab catch
1995-96	3383	10149	7270	2.15	0.71	59.63
1996-97	2668	8004	5259	1.96	0.66	61.37
1997-98	2525	7575	4675	1.85	0.62	68.31
Total	8576	25728	17204	2.01	0.67	62.32

The maximum catch of *P. pelagicus* was reported during the month of July in first year, March in second year and May in third year. Month wise catch details are given in the figures 2.11 to 2.13.

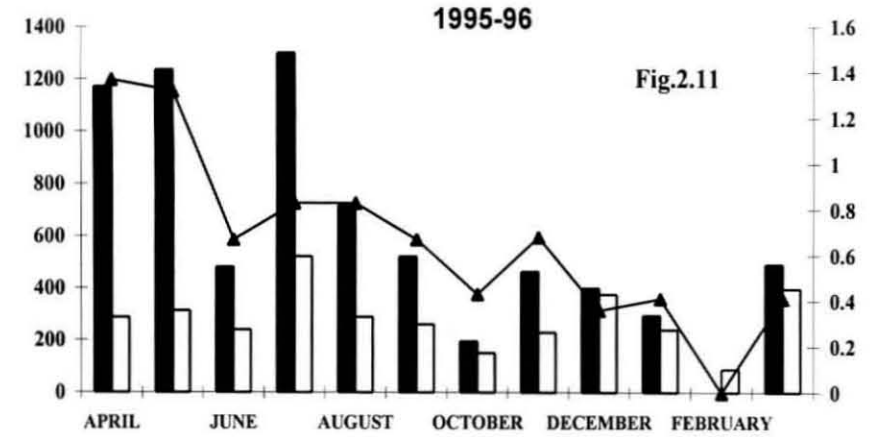
Size composition

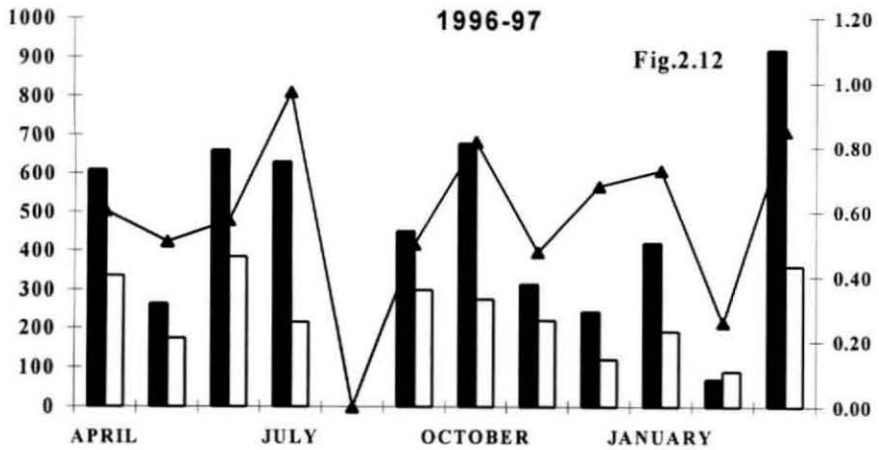
At Mandapam (Palk Bay) the fishery was contributed by the size groups ranging from 70-195 mm crabs. The major portion of the catch was contributed by 105-170 mm group in both the sexes. The recorded maximum size of male and female was 195 mm and 193 mm (carapace width) respectively. In males the dominant size class was 136-140 mm in all the three years and in pooled data it was observed that 131-140 mm size group dominated the fishery. In females the dominant size class was 126-130 mm for the first year and 131-135 mm for the second and third years (Figures 2.14 to 2.19).

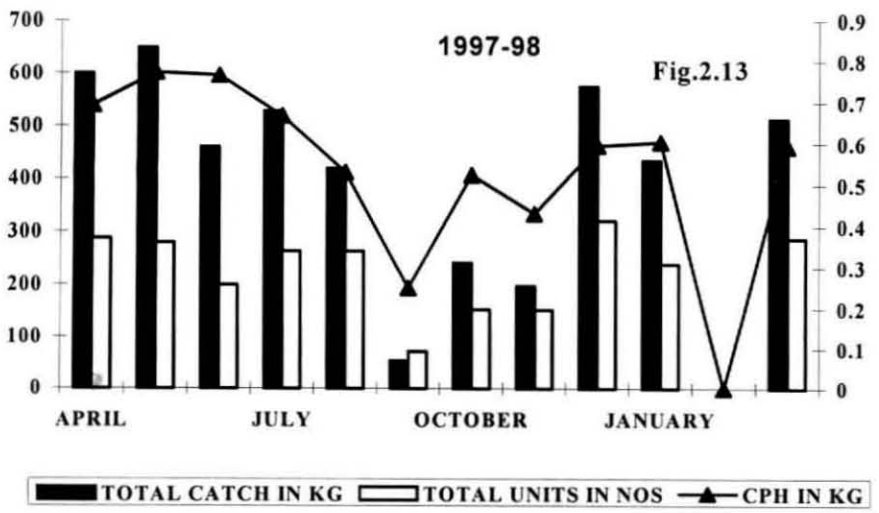
At Gulf of Mannar side of Mandapam, the fishery was contributed by the crabs of size range 81-180 mm size groups. Dominant size group during 1996-97 period was 106-110 in males and 126-130 mm in females. In 1997-98 the dominant group was 126-130 mm in both the sexes. In pooled data of males and females the dominant class was 121-130 mm. The maximum sizes observed for male and female were 178 mm and 173 mm respectively (Figures 2.20 to 2.23).

At Devipattinam, fishery was contributed by size range of 81-160 mm with negligible (>1%) catch of bigger sizes in the year 1996-97. The maximum recorded

TOTAL ESTIMATED CATCH AND EFFORT AT THOPPUKKADU







SIZE DISTRIBUTION OF MALES AT MANDAPAM (PALK BAY)

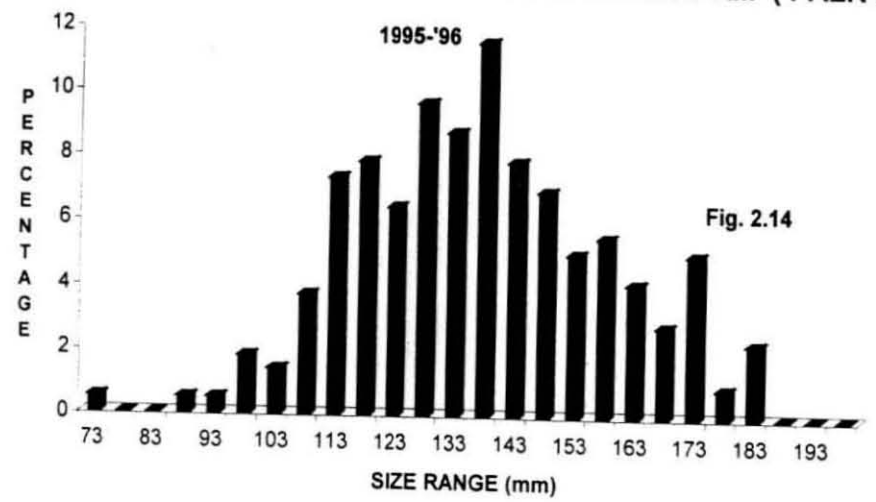


Fig. 2.14

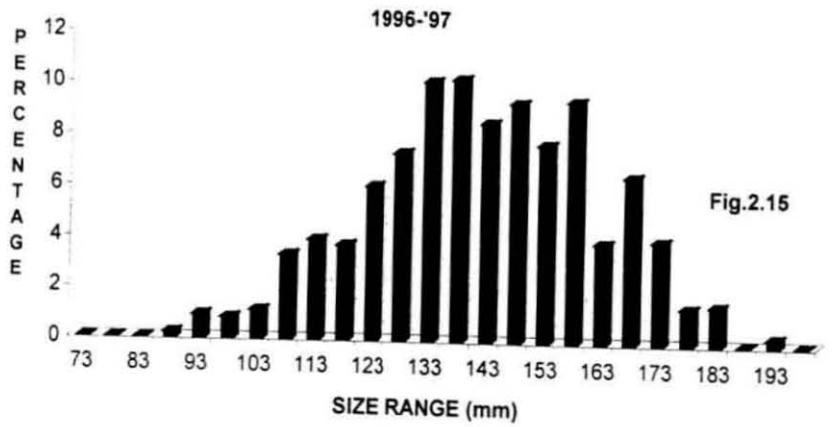


Fig.2.15

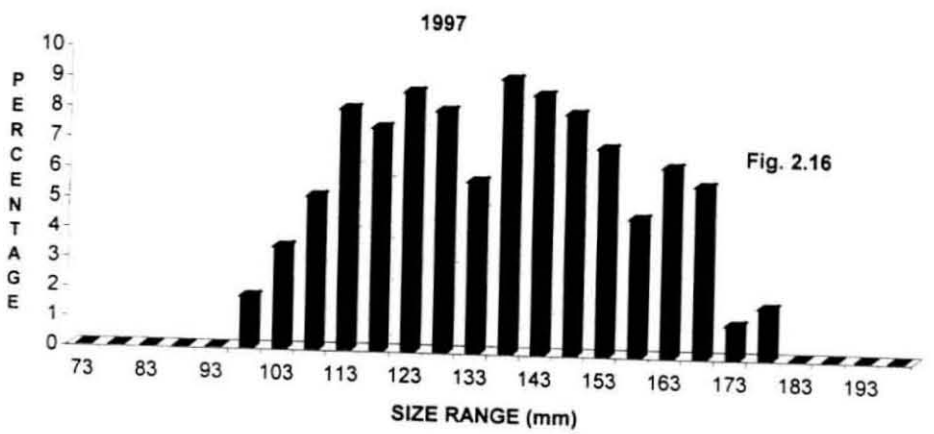


Fig. 2.16

SIZE DISTRIBUTION OF FEMALES AT MANDAPAM (PALK BAY)

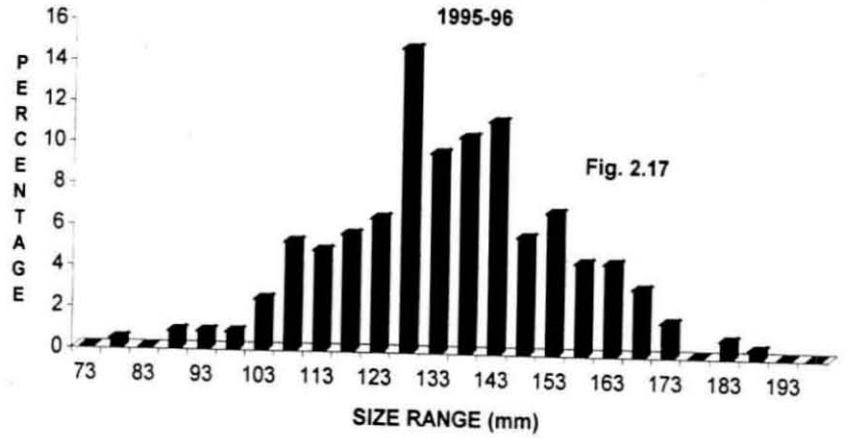


Fig. 2.17

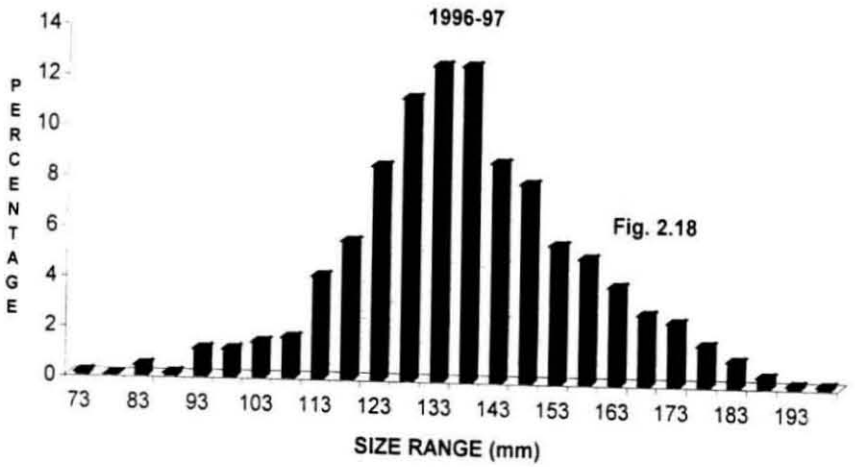


Fig. 2.18

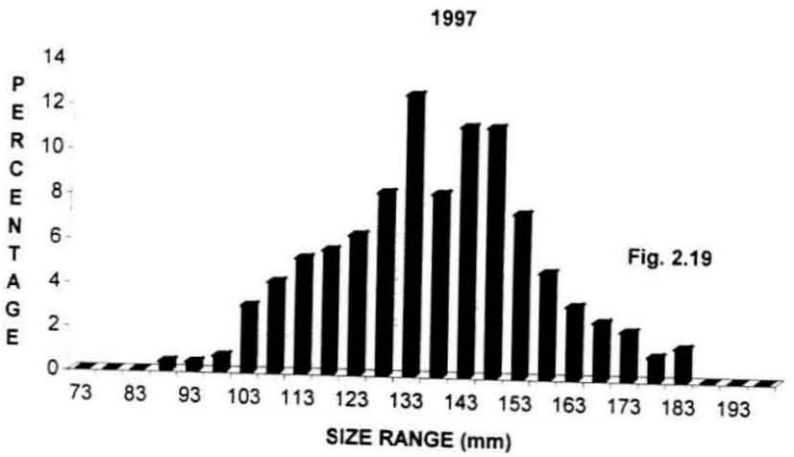


Fig. 2.19

SIZE DISTRIBUTION OF MALES AT MANDAPAM (GULF OF MANNAR)

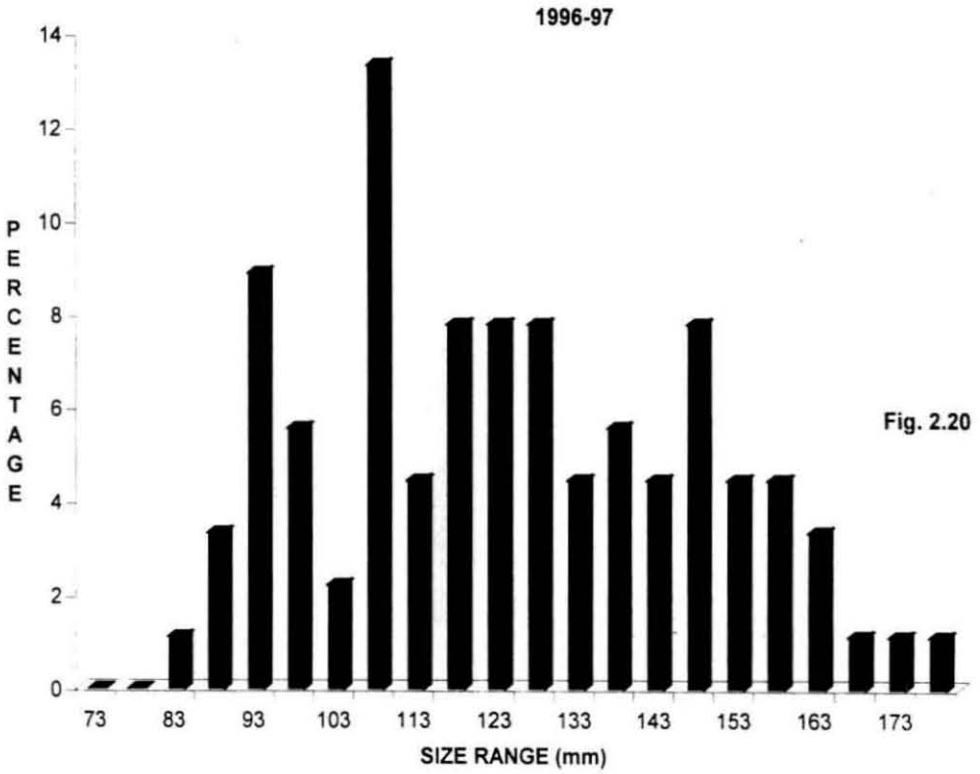


Fig. 2.20

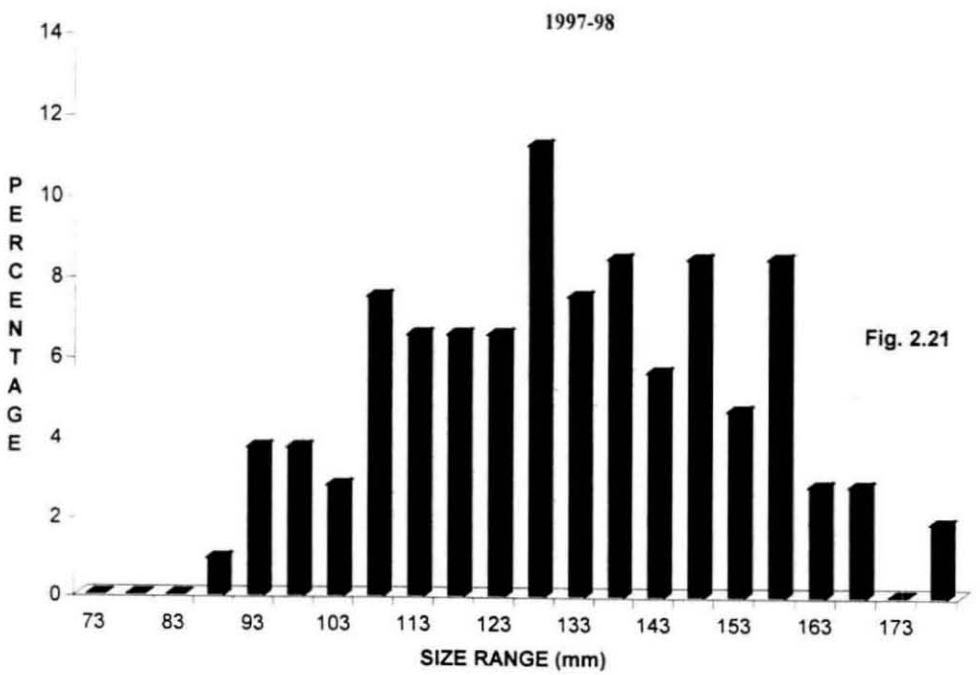


Fig. 2.21

SIZE DISTRIBUTION OF FEMALES AT MANDAPAM (GULF OF MANNAR)

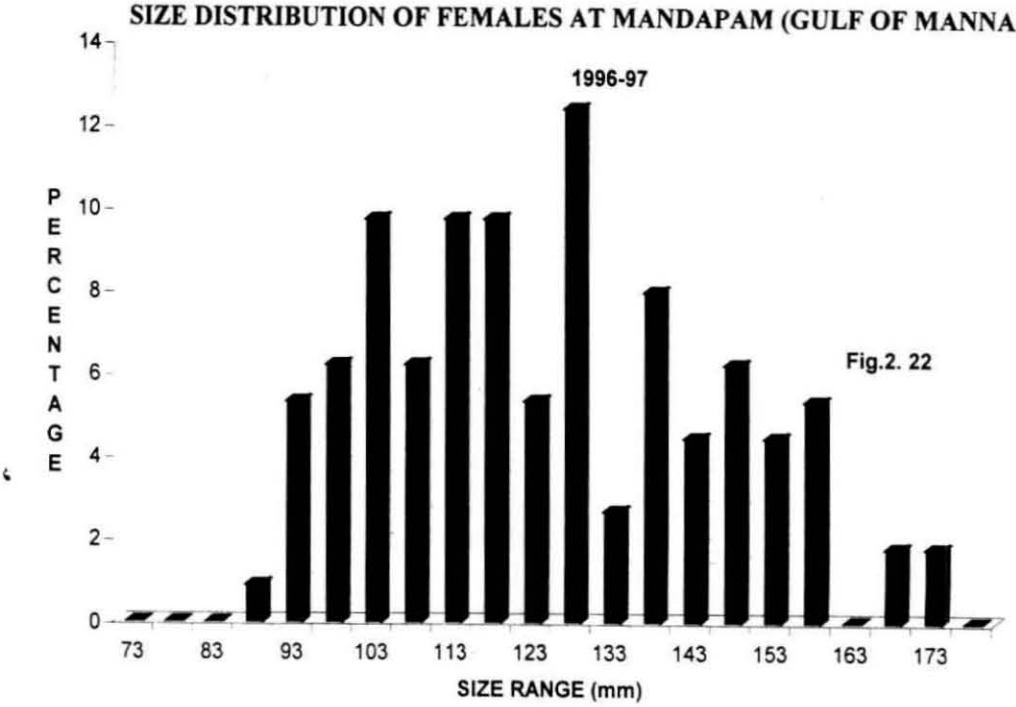


Fig.2. 22

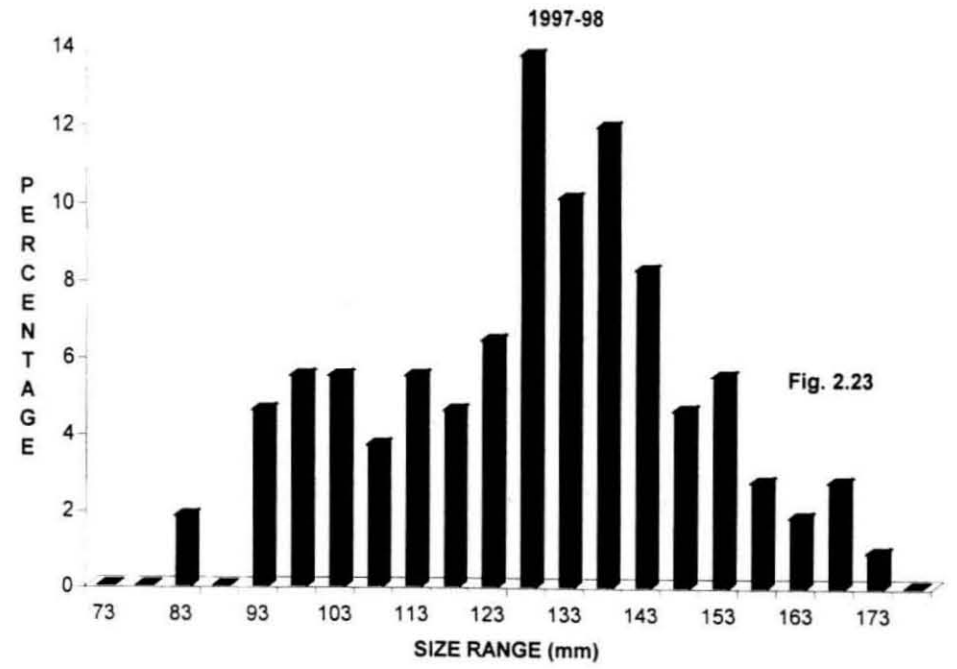


Fig. 2.23

sizes for male and female were 182 and 176 mm respectively. In males the dominating size group was 126-130 mm in the first year and 121-125 mm in the second and third years. In females different size groups were dominating during the period of study *i.e.* 121-125 mm in 1995-96, 126-130 mm in 1996-97 and 106-110 mm in 1997-98. The bulk of the catch was comprised of size range 101-150 mm in both sexes. In a pooled data of males and females the dominating size group was 121-130 mm (Figures 2.24 to 2.29).

In Thoppukadu, the crab landings were in a size range of 81-160 mm. The maximum sizes recorded for male and female were as 156 and 159 mm respectively. The dominating size group in males was 121-125 mm for the first two years and third year it was 106-110 mm. In females it was 121-125 mm, 116-120 mm and 126-130 mm for the first, second and third years respectively. The major portion of the crab landings was comprised of 101-140 mm size groups in both sexes. In the pooled data of sexes the dominant size group recorded was 111-120 mm (Figures 2.30 to 2.35).

The catch represented all maturity stages in both sexes and are described in the next chapter under biology. In females, the berried crabs were observed in the catch throughout the year in trawl catches, but the percentage was found fluctuating in different months in all the three years. However, during April-July 1997, bulk of the female population was in berried condition.

At Mandapam (Palk Bay) highest (43.8%) percentage of immature females were observed during June 1996 and lowest (2.2%) during June 1997. Mature (but not berried) female percentage was highest (71.1%) during August 1996 and lowest (18.8%) during January 1996. Berried females (III & IV) stages) were highest during June 1997 *i.e.* 67.8% and lowest (11.4%) during September 1995. Parasite infected crabs were maximum during April 1996 (7.7%) and in many months it was not observed in catches. At Gulf of Mannar side off Mandapam, immature crabs were high (50.00%) during October 1996 and lowest (8.00%) report was in March 1997. Mature females landed maximum during December 1997 (61.11%) and lowest occurrence was in February 1998 (16.67%). Percentage of berried females was more in March 1997 and less in December 1997. Parasitic infestation was found ranging between 0 and 16.8% during the period of study.

SIZE DISTRIBUTION OF MALES AT DEVIPATTINAM

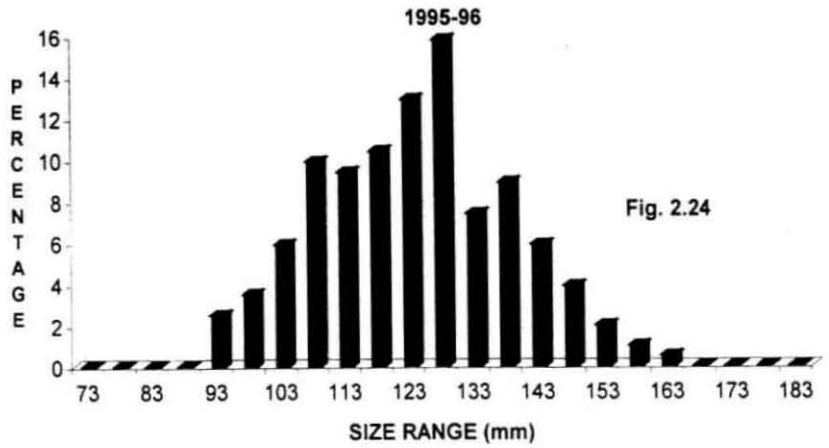


Fig. 2.24

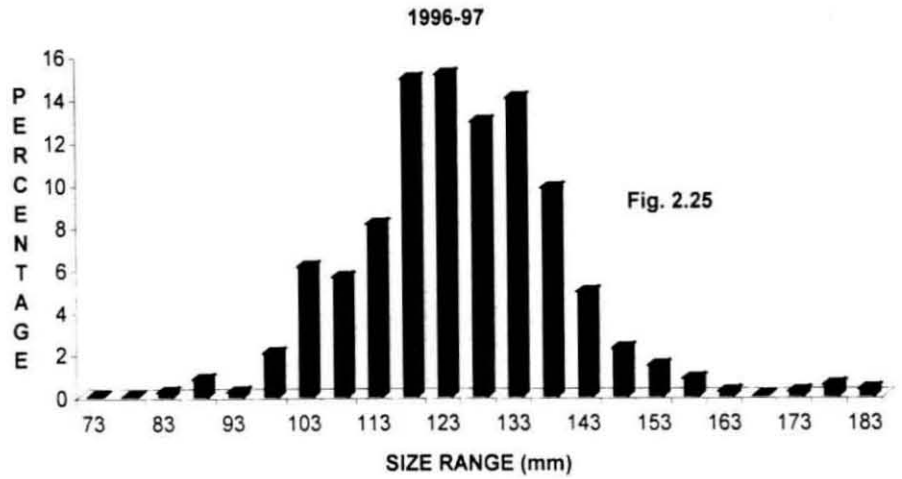


Fig. 2.25

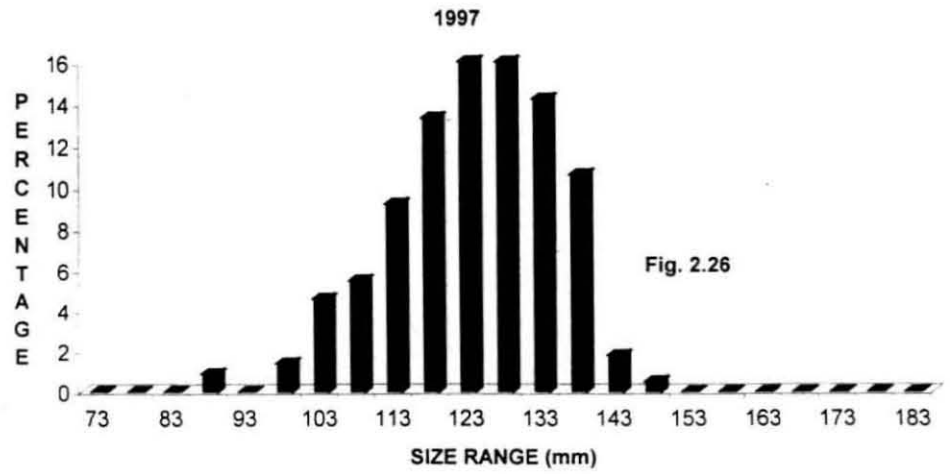


Fig. 2.26

SIZE DISTRIBUTION OF FEMALES AT DEVIPATTINAM

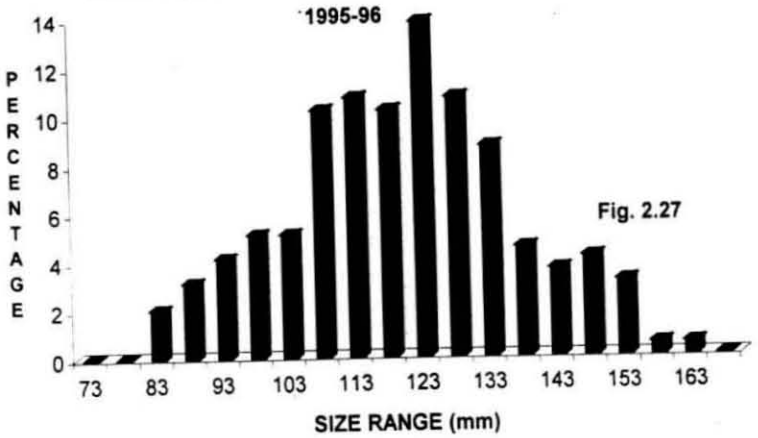


Fig. 2.27

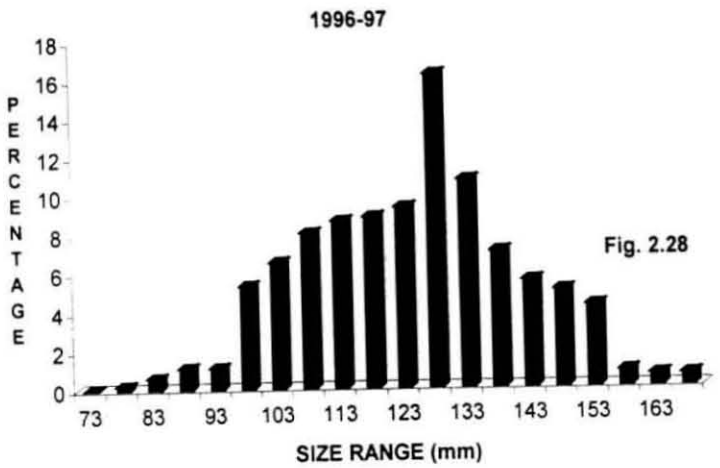


Fig. 2.28

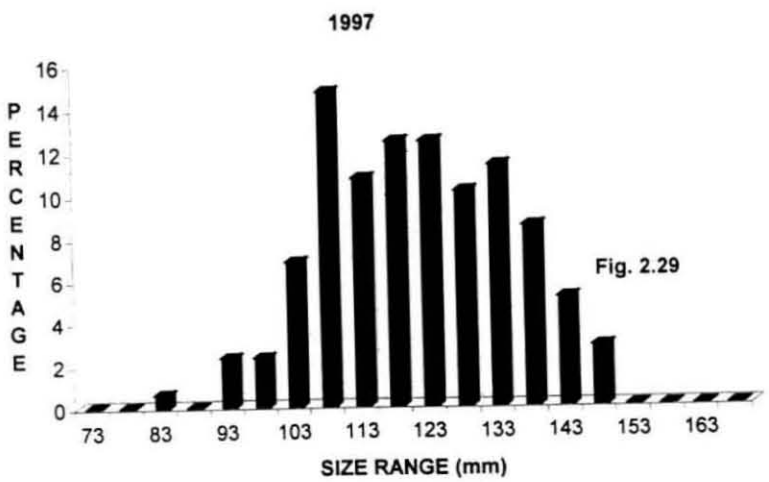


Fig. 2.29

SIZE DISTRIBUTION OF MALES AT THOPPUKKADU

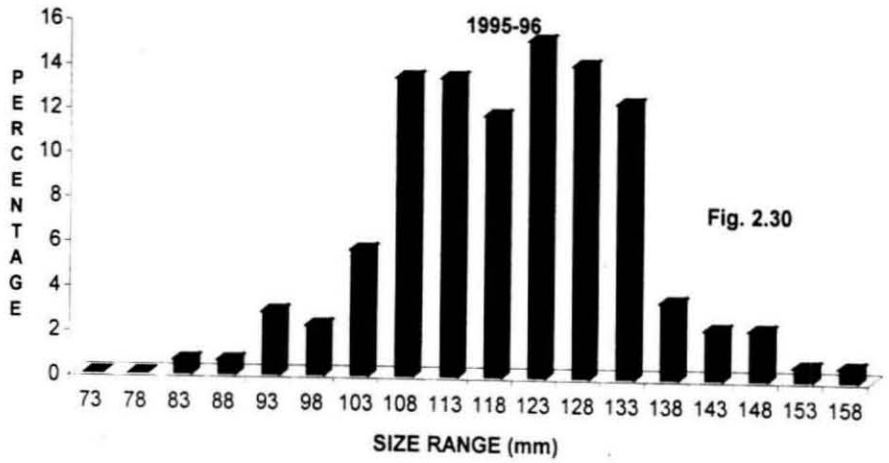


Fig. 2.30

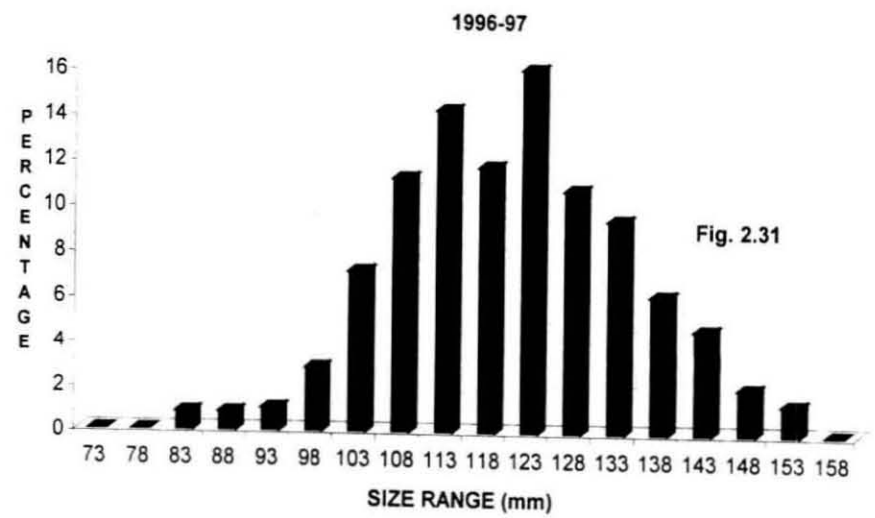


Fig. 2.31

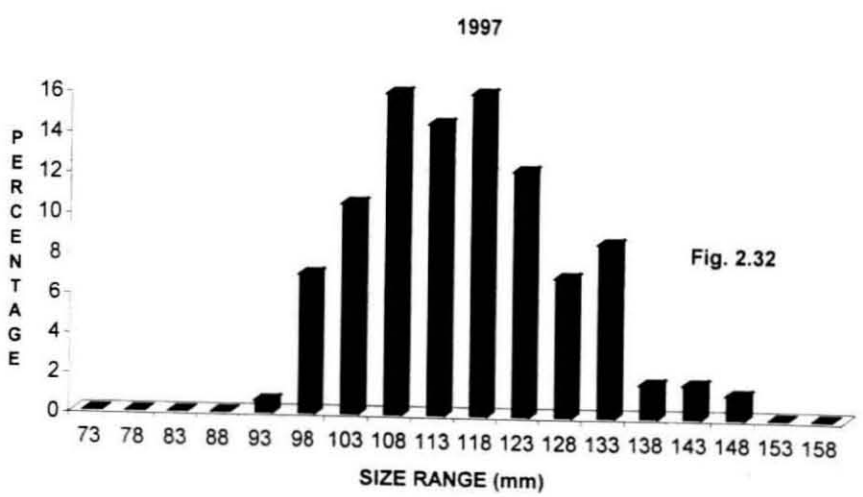


Fig. 2.32

SIZE DISTRIBUTION OF FEMALES AT THOPPUKKADU

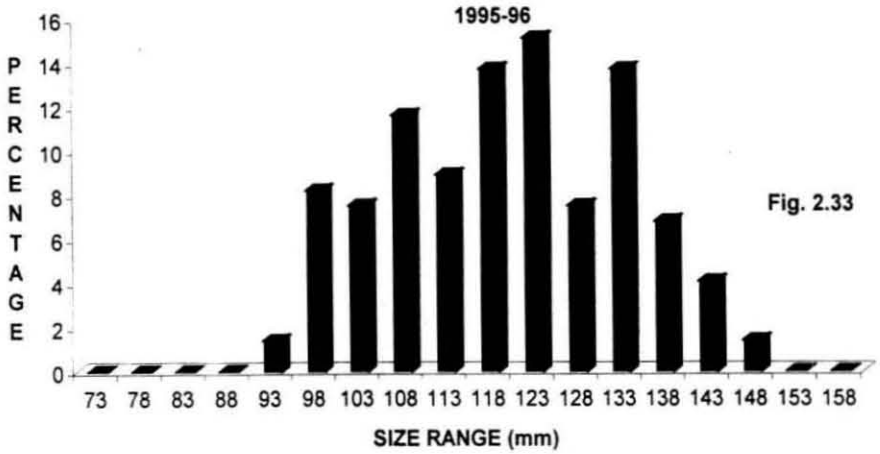


Fig. 2.33

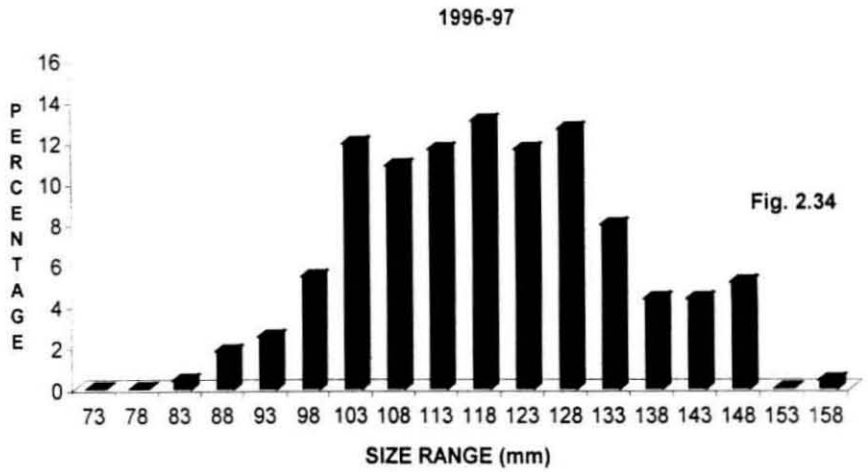


Fig. 2.34

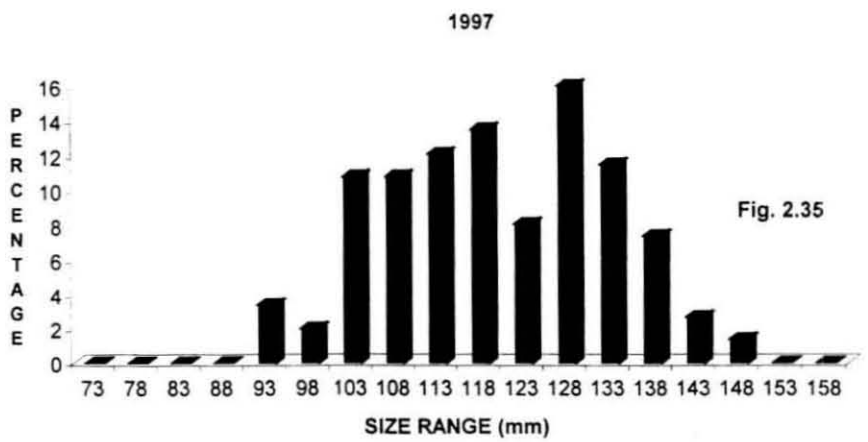


Fig. 2.35

At Devipattinam the occurrence of immature crabs varied between 6.7-57.1% during March 1997 and November 1995 respectively. The highest percentage of mature crabs was noticed in August 1997 (79.2%) and lowest during October 1995 (16.7%). The maximum representation of the berried females in the catch was observed during August 1995 (38.7%) and lowest during June 1996 (28.6%) and in several months there were no reports of berried female at all. (The data of the month May 1996 not included for the comparative studies as the sample size was very small).

At Thoppukadu, in the month of October 1995 immature crabs constituted the entire sample. The lowest percentage was recorded in August 1995 (11.1%). Maximum and minimum occurrence of mature crabs was reported during August 1995 (66.7%) and September 1996 (12.5%). Berried females were maximum during September 1996 and not at all present in the catch in many months. Parasite infected crabs were recorded in maximum numbers during January 1996 and there was no report of parasitic infestations during several other months (Fig. 2.36 to 2.38).

Probability of capture

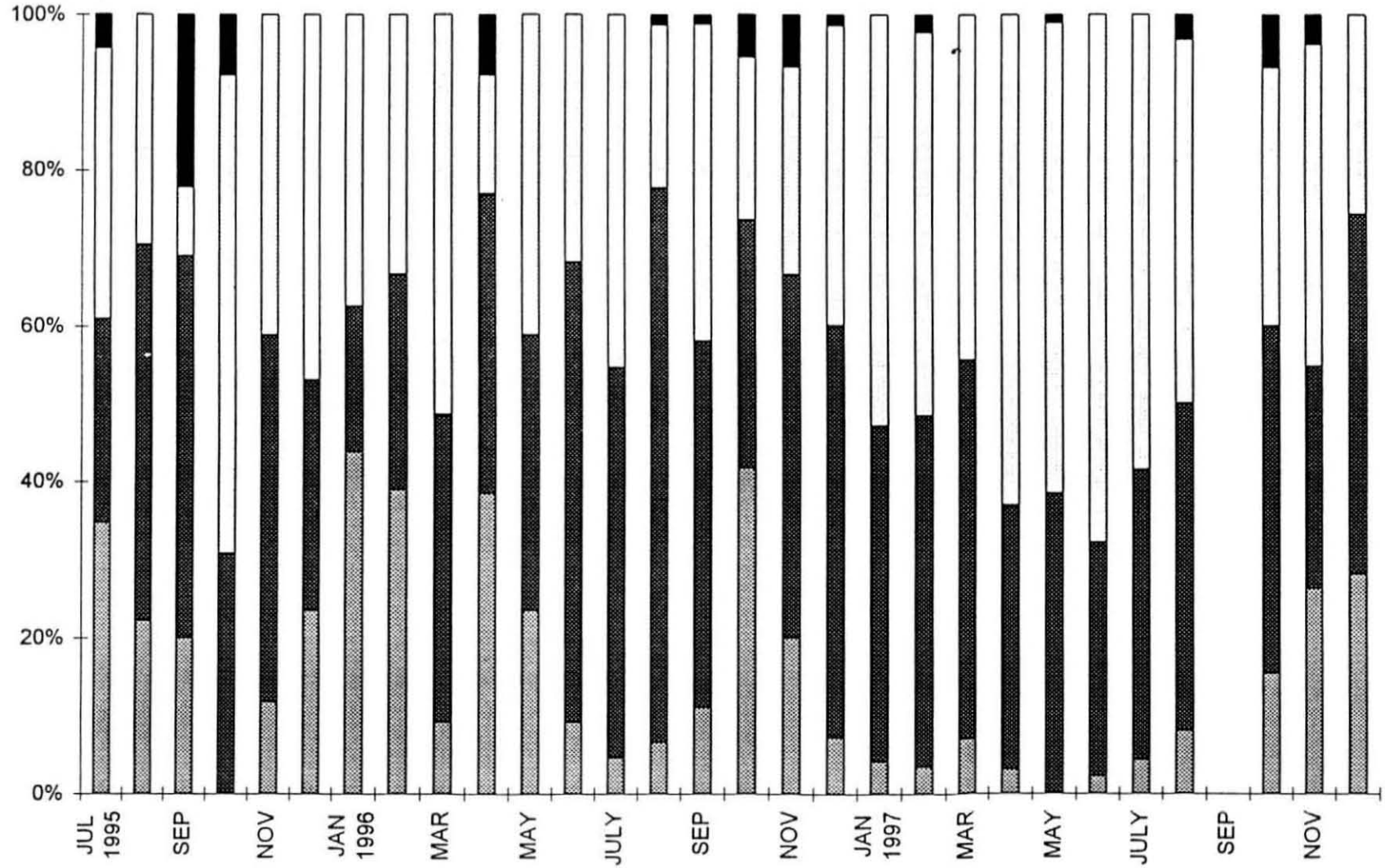
Probability of capture analysis estimated the length(carapace width) at which 25%, 50% and 75% (L-25; L-50 and L-75) crabs are retained and rest in each category escapes through the meshes. In males the L-25; L-50 and L-75 values were 115.21, 124.68 and 130.39mm respectively (Fig.2.39) and a carapace width of 137mm and above, all the crabs were retained by the trawl net. In females these values were 115.39, 122.98 and 129.01mm respectively (Fig. 2.40) and a carapace width of 142 mm and above, all the crabs were caught by the trawl net.

Yield-per-recruit (Y/R)

The results of the relative yield-per-recruit in males and females are given in the following table and fig. 2.41 and 2.42.

Sex	E-max	E-0.1	E-0.5
Male	0.6382	0.6206	0.3712
Female	0.6481	0.6101	0.3788

Fig. 2.36. Monthwise distribution of maturity stages at Mandapam



▨ **IM**- Immature crabs; ■ **M**- Mature, but not berried;
□ **B**- Berried crabs; ■ **P**- Parasitised crabs.

Fig. 2.37. Monthwise distribution of maturity stages at Devipattinam

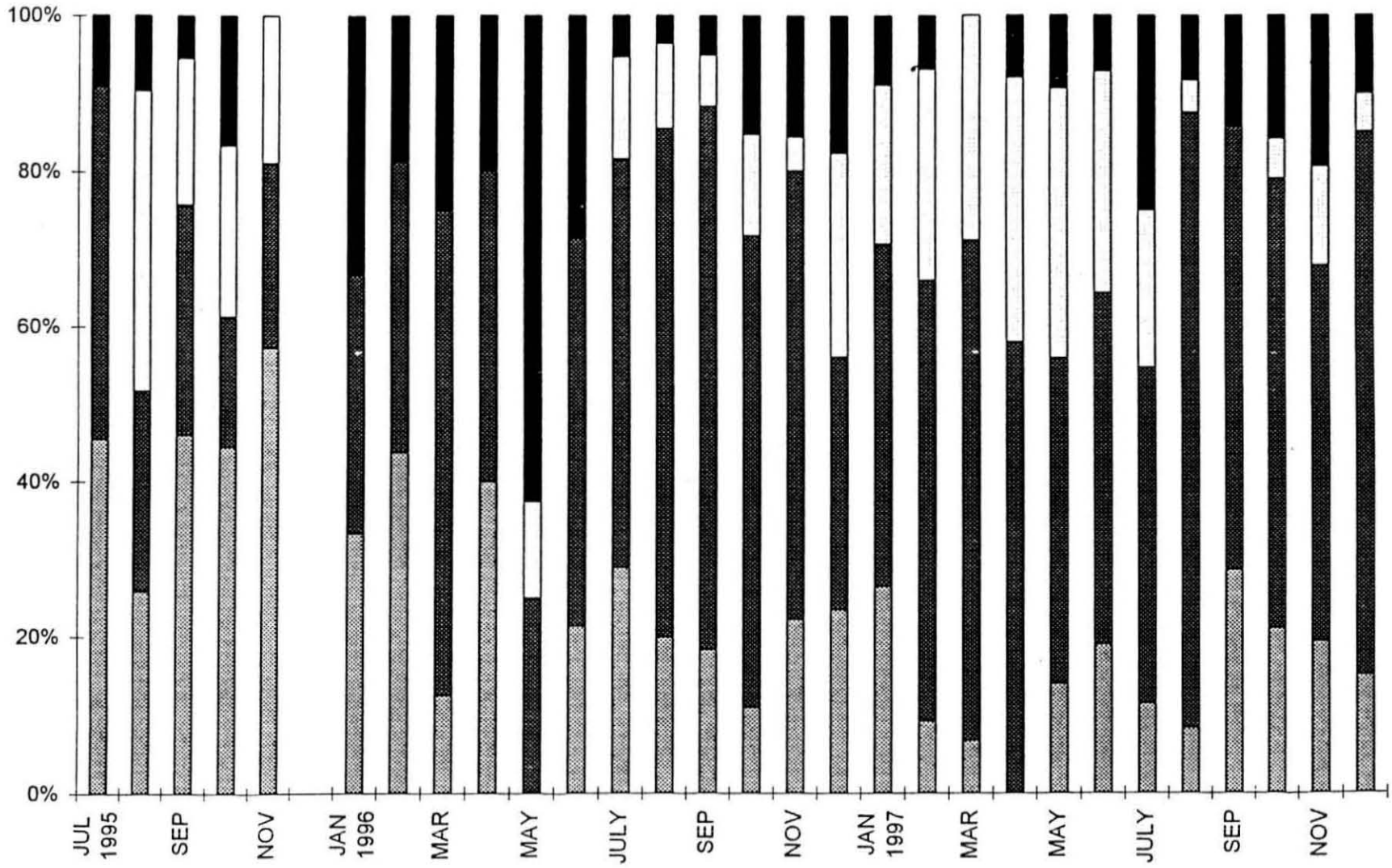
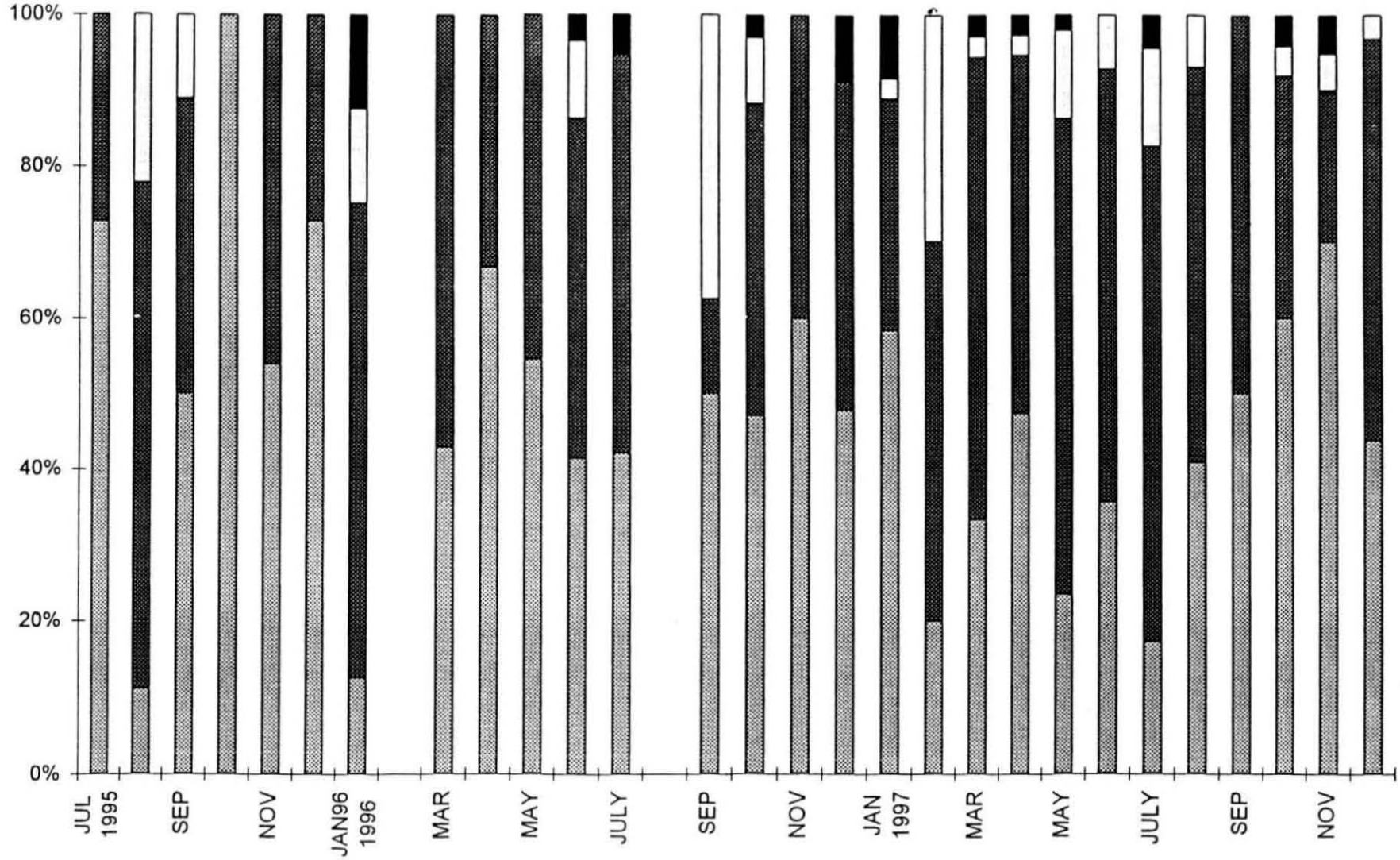


Fig. 2.38. Monthwise distribution of maturity stages at Thoppukadu



IM- Immature crabs; **M**- Mature, but not berried;

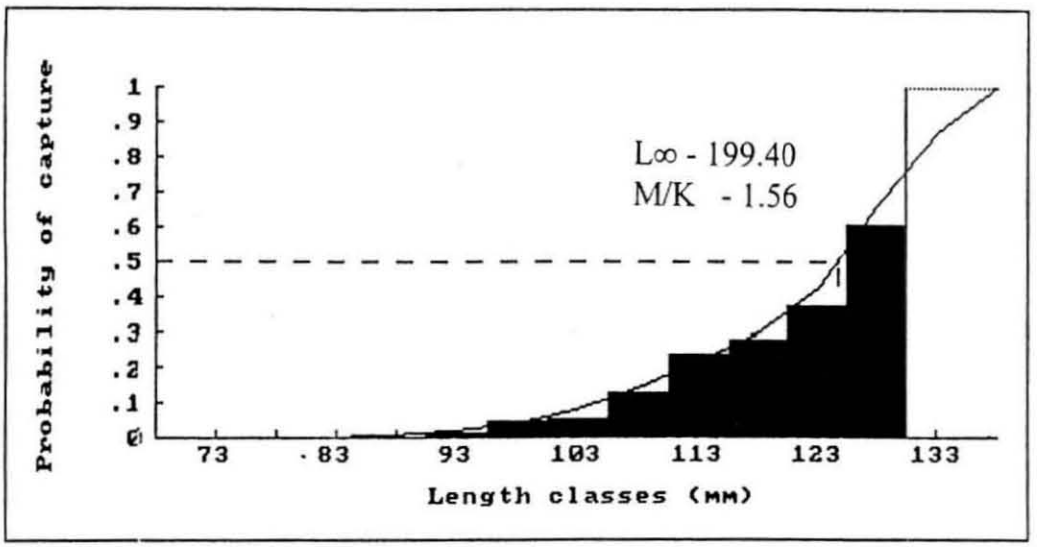


Fig. 2.39. Probability of Capture Analysis in *Portunus pelagicus* Males.
L-25 : 115.2 ; L-50 : 124.68 ; L-75 : 130.39 (mm)

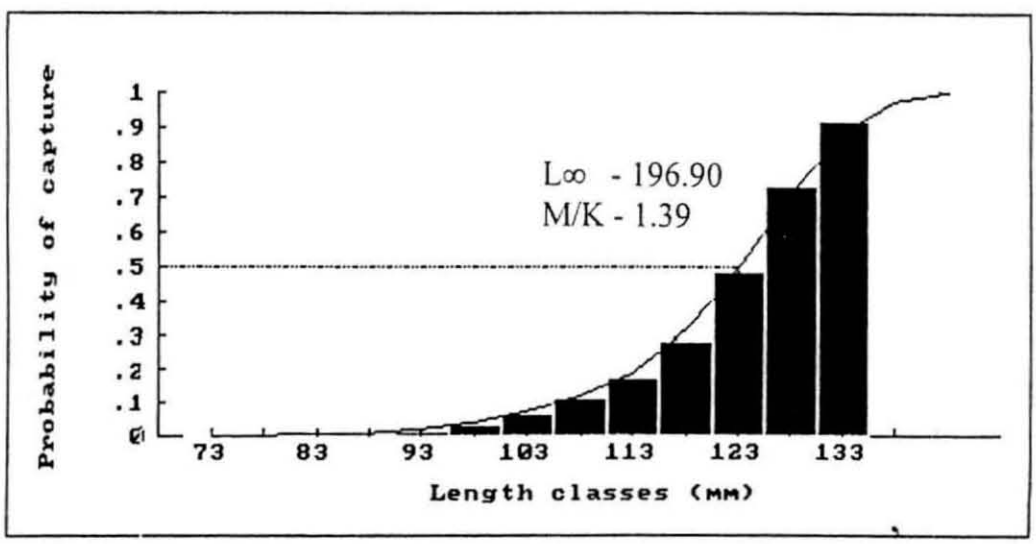


Fig. 2.40. Probability of Capture Analysis in *Portunus pelagicus* Females.
L-25 : 115.39 ; L-50 : 122.98 ; L-75 : 129.01 (mm)

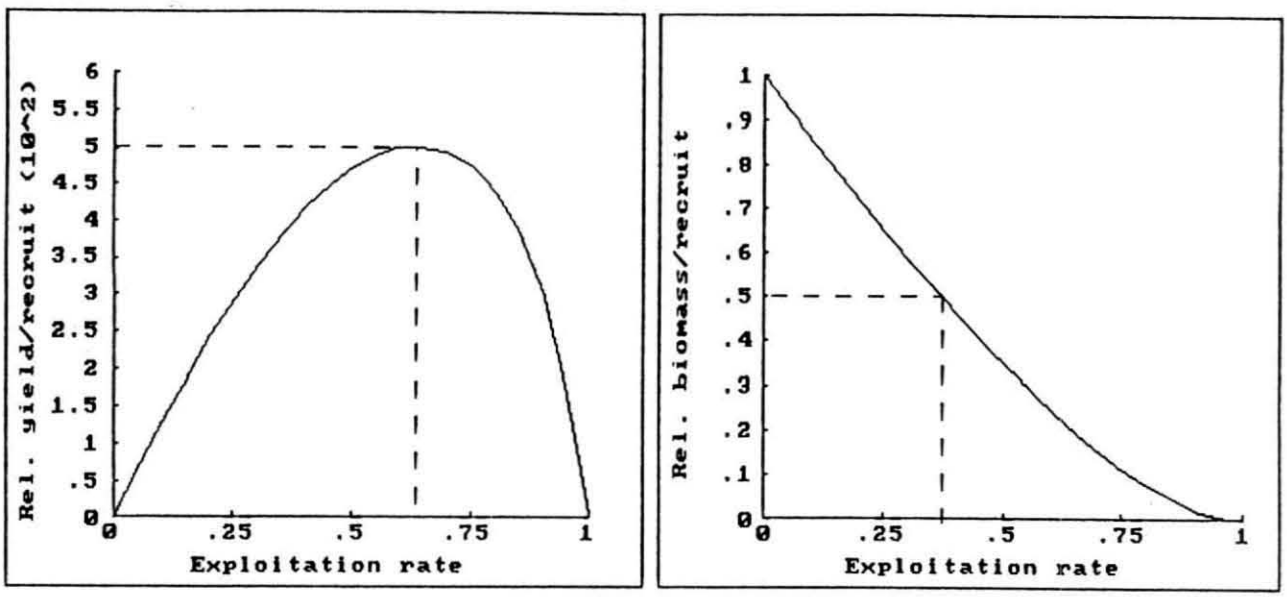


Fig. 2.41. Yield per Recruit Analysis in *Portunus pelagicus* Males.
E-max : 0.6382 ; E-0.1:0.6206 ; E-0.5 : 0.3712

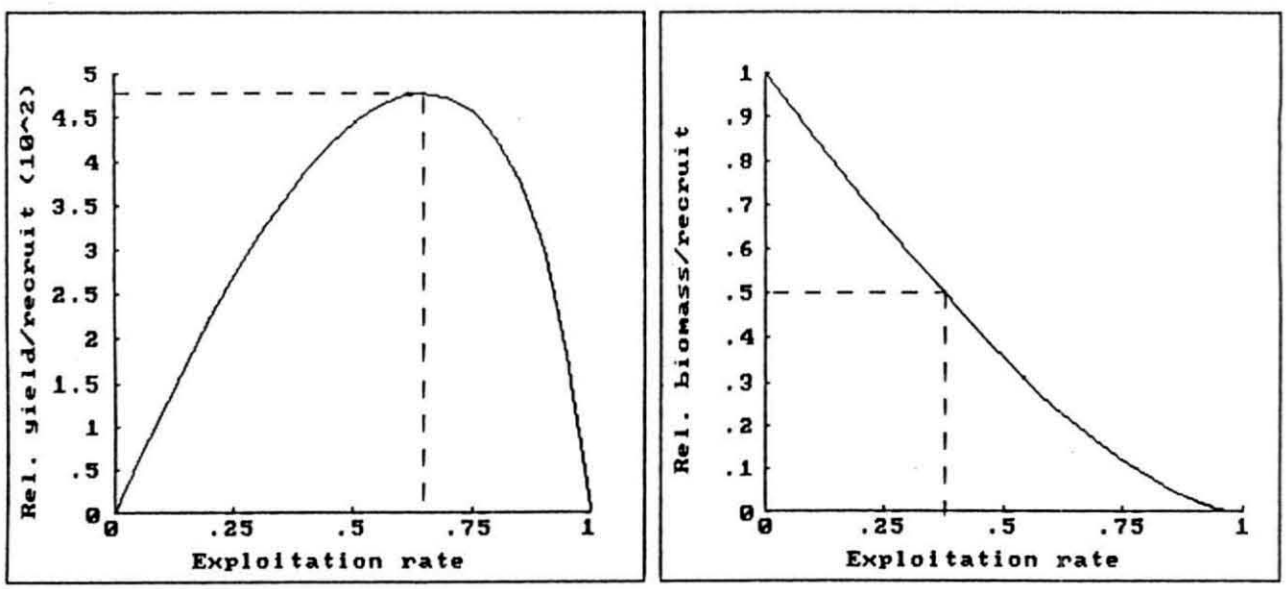


Fig. 2.42. Yield per Recruit Analysis in *Portunus pelagicus* Females.
E-max : 0.6481 ; E-0.1:0.6101 ; E-0.5 : 0.3788

The total instantaneous mortality coefficient (Z)

The 'Z' estimated by length converted catch curve method was 4.54 in males and 3.03 females (Fig. 2.43 and 2.44).

The instantaneous natural mortality coefficient (M)

The 'M'estimate in males by Rikhter and Efanov (1976) and Pauly's (1980) was 2.09 and 2.76. In females 'M' was 1.46 and 2.11 respectively by the two methods.

The instantaneous fishing mortality coefficient (F)

The 'F' was 2.45 in males and 1.57 in females. The exploitation rate (**E**) was almost similar in males and females *i.e.* 0.54 and 0.52 respectively.

Growth parameters

In males, the $L\infty$ values estimated using different methods ranged between 191.9 and 223.0 mm while in females it was between 190.0 and 196.9 mm (Fig. 2.45 to 2.50 and Tables 2.1 to 2.2). The 'K' values were in a range of 0.95-1.71 and 1.00 –1.42 in males and females respectively. The growth parameters obtained in different approaches are given in the following table.

Method	$L\infty$ (mm)	K	Observed L_{max} (mm)	Growth Equation
Male				
Gulland and Holt	199.4	1.56	195.0	$L_{(t)} = 199.4 \{1\text{-}exp^{-1.56 (t-t_0)}\}$
Munro's	191.9	1.68		$L_{(t)} = 191.9 \{1\text{-}exp^{-1.68 (t-t_0)}\}$
Fabens	195.0	1.71		$L_{(t)} = 195.0 \{1\text{-}exp^{-1.71 (t-t_0)}\}$
ELEFAN	223.0	0.95		$L_{(t)} = 223.0 \{1\text{-}exp^{-0.95 (t-t_0)}\}$
Female				
Gulland and Holt	196.9	1.05	193.0	$L_{(t)} = 196.9 \{1\text{-}exp^{-1.05 (t-t_0)}\}$
Munro's	190.4	1.37		$L_{(t)} = 190.4 \{1\text{-}exp^{-1.37 (t-t_0)}\}$
Fabens	190.0	1.42		$L_{(t)} = 190.0 \{1\text{-}exp^{-1.42 (t-t_0)}\}$
ELEFAN	195.1	1.00		$L_{(t)} = 195.1 \{1\text{-}exp^{-1.00 (t-t_0)}\}$

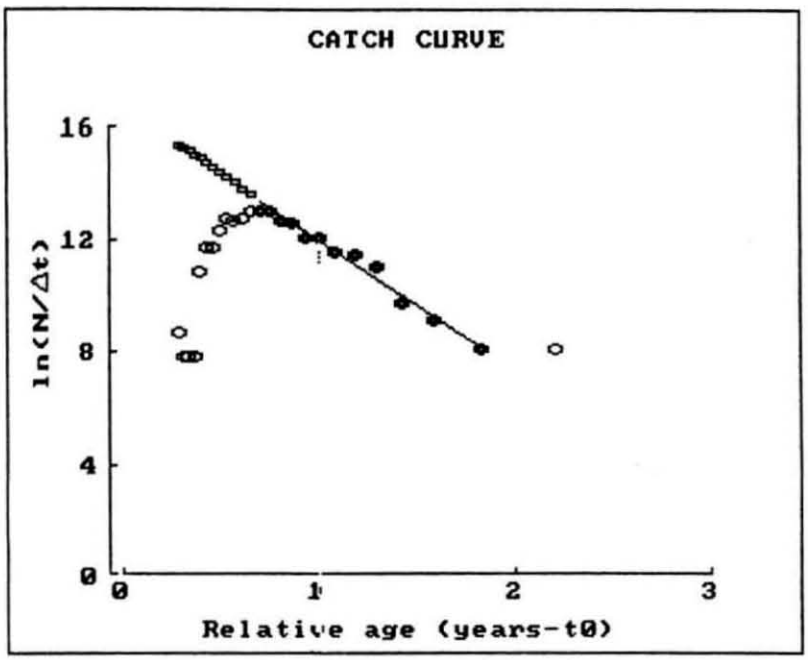


Fig. 2.43. Catch curve - *Portunus pelagicus* Males.
Cutoff length (L')-130.5; Mean length(from L')-149.63 ; Z from the catch curve-4.54 ;
Natural Mortality (M, for T=29^0 C)-2.72 ; M value used-2.09 ;
Fishing mortality (F=Z-M)-2.45; Exploitation rate (E=F/Z)-0.54.

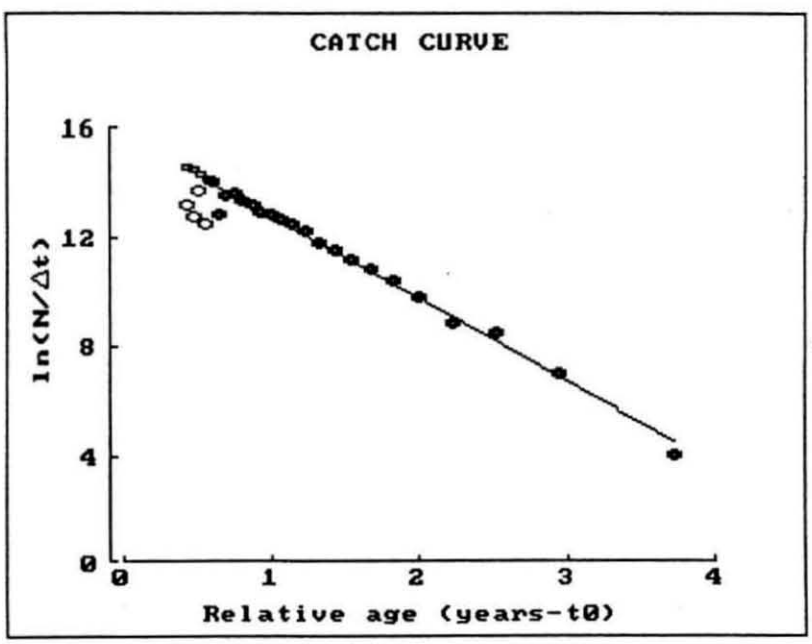


Fig. 2.44. Catch curve - *Portunus pelagicus* Females.
Cutoff length (L')-90.5; Mean length (from L')-120.52 ; Z from the catch curve-3.03 ;
Natural Mortality (M, for T=29^0 C)-2.11 ; M value used-1.46 ;
Fishing mortality (F=Z-M)-1.57; Exploitation rate (E=F/Z)-0.52.

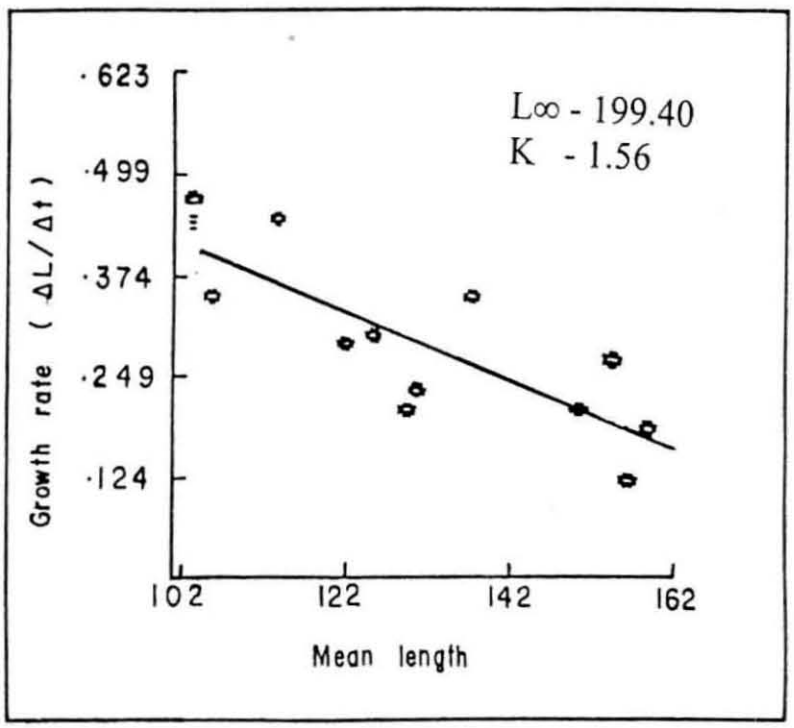


Fig. 2.45. VBGF derived from Gulland and Holt method in *Portunus pelagicus* Males.

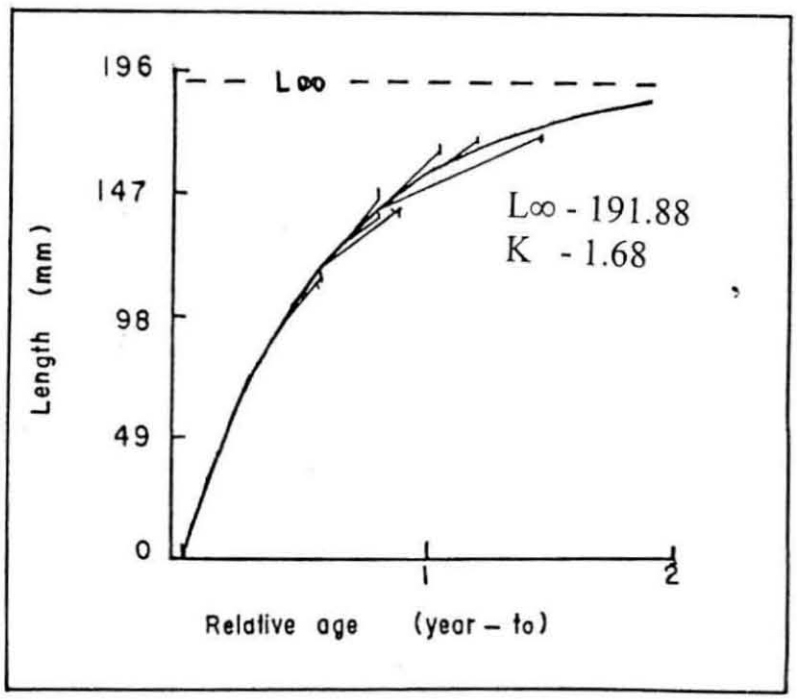


Fig. 2.46. VBGF derived from Fabens method in *Portunus pelagicus* Males.

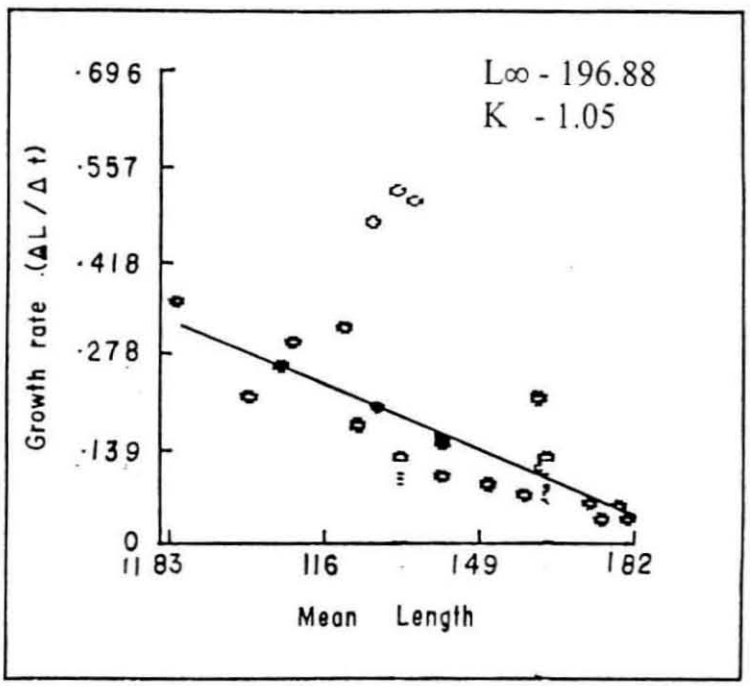


Fig. 2.47. VBGF derived from Gulland and Holt method in *Portunus pelagicus* Females.

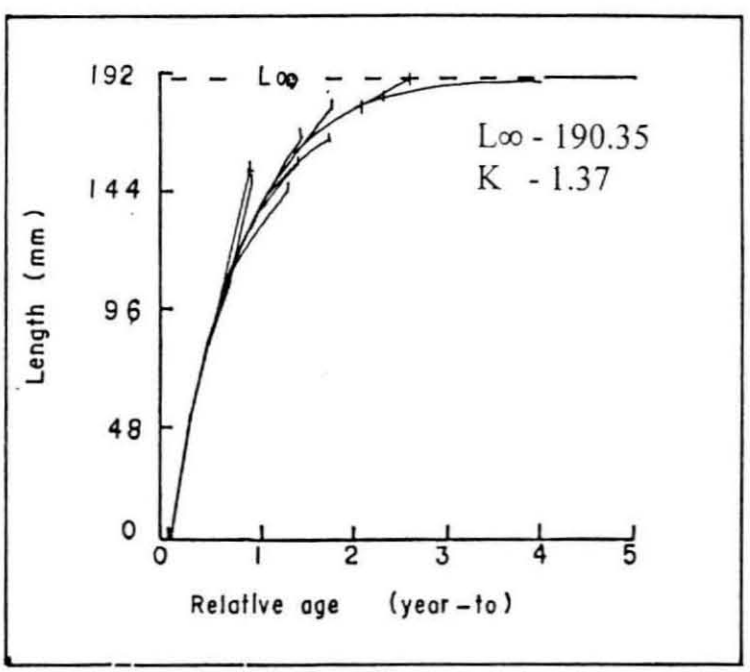


Fig. 2.48. VBGF derived from Fabens method in *Portunus pelagicus* Females.

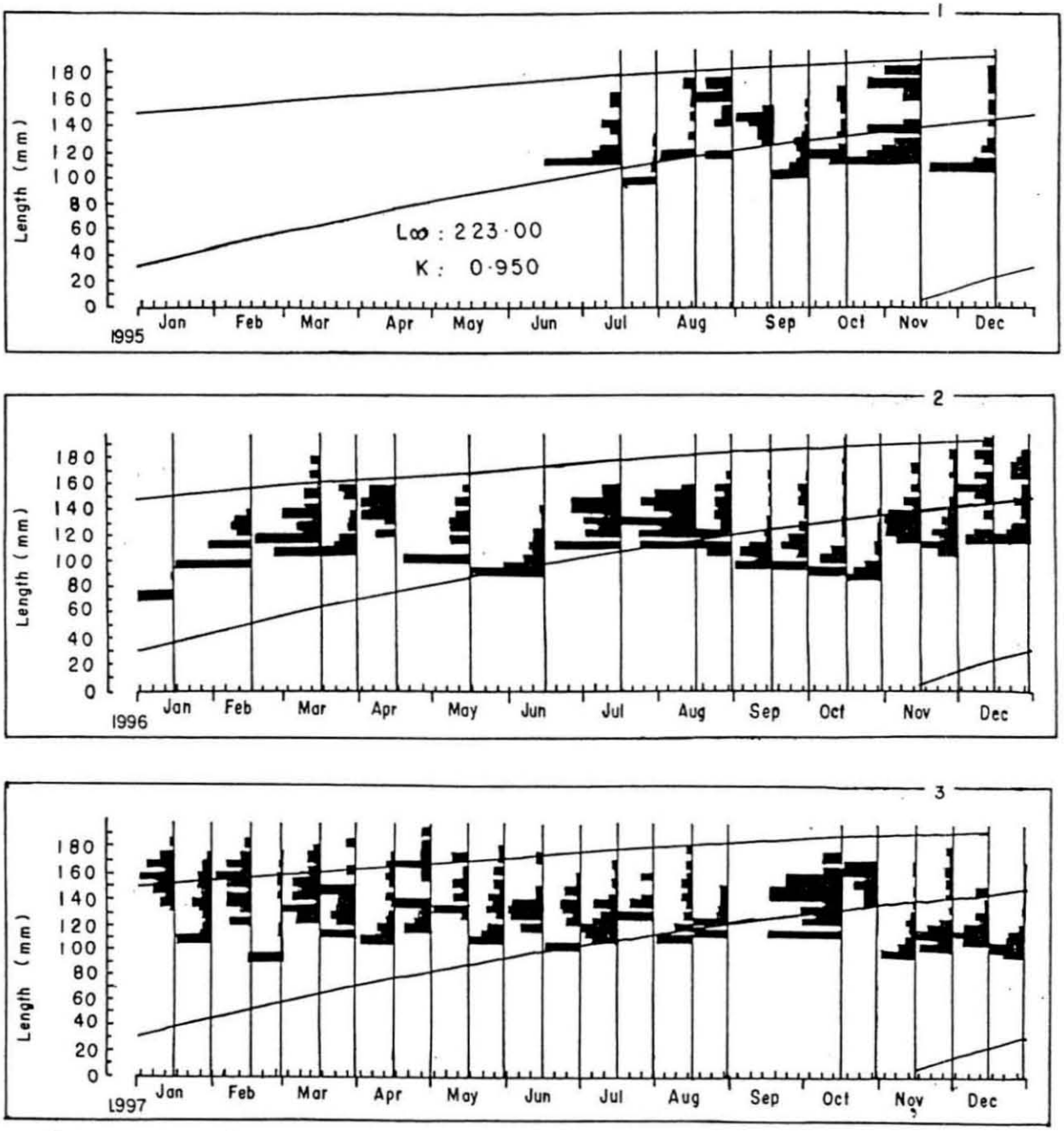


Fig. 2.49. VBGF derived from ELEFAN method in *Portunus pelagicus* Males.

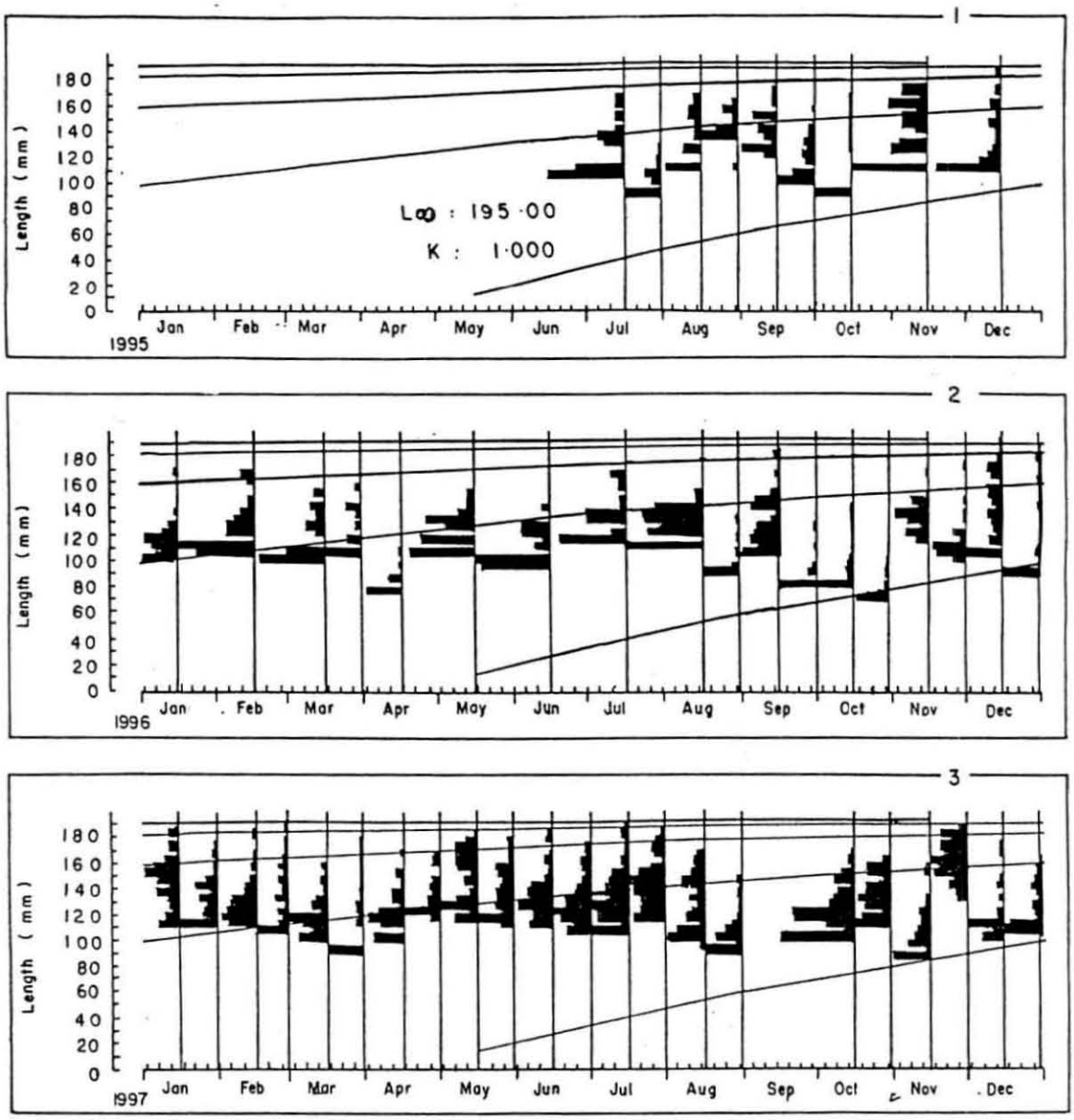


Fig. 2.50. VBGF derived from ELEFAN method in *Portunus pelagicus* Females.

Table.2.1. MONTHLY GROWTH OF WILD MALES OF *PORTUNUS PELAGICUS* (BASED ON THE VBGF)

	$L_\infty \longrightarrow$	199.4	191.9	195.0
AGE	K $\longrightarrow$	1.56	1.68	1.71
MONTH	YEAR			
1	0	24.3	25.1	25.9
2	0	45.6	46.9	48.4
3	0	64.4	65.8	67.8
4	0	80.8	82.3	84.7
5	0	95.3	96.6	99.4
6	0	108.0	109.0	112.1
7	0	119.1	119.9	123.1
8	0	128.9	129.3	132.6
9	0	137.5	137.5	140.9
10	0	145.0	144.6	148.1
11	0	151.7	150.7	154.3
12	1	157.5	156.1	159.7
13	1	162.6	160.8	164.4
14	1	167.1	164.9	168.5
15	1	171.0	168.4	172.0
16	1	174.3	171.5	175.1
17	1	177.5	174.1	177.7
18	1	180.2	176.4	180.0
19	1	182.5	178.5	182.0
20	1	184.6	180.2	183.7
21	1	186.4	181.7	185.2
22	1	187.9	183.1	186.5
23	1	189.3	184.2	187.6
24	2	190.6	185.2	188.6
25	2	191.6	186.1	189.5
26	2	192.6	186.8	190.2
27	2	193.4	187.5	190.8
28	2	194.1	188.1	191.4
29	2	194.8	188.6	191.9
30	2	195.3	189.0	192.3
31	2	195.8	189.4	192.6
32	2	196.2	189.7	193.0
33	2	196.6	190.0	193.2
34	2	197.0	190.2	193.5
35	2	197.3	190.5	193.7
36	3	197.5	190.6	193.8

Table.2.2. MONTHLY GROWTH OF WILD FEMALES OF *PORTUNUS PELAGICUS* (BASED ON THE VBGF)

	$L_\infty \longrightarrow$	196.9	190.4	190.0
AGE	K $\longrightarrow$	1.05	1.37	1.42
MONTH	YEAR			
1	0	16.5	20.5	21.2
2	0	31.6	38.9	40.0
3	0	45.5	55.2	56.8
4	0	58.1	69.8	71.7
5	0	69.8	82.8	84.9
6	0	80.4	94.4	96.6
7	0	90.2	104.8	107.0
8	0	99.1	114.0	116.3
9	0	107.3	122.2	124.5
10	0	114.8	129.6	131.8
11	0	121.7	136.1	138.3
12	1	128.0	142.0	144.1
13	1	133.8	147.2	149.2
14	1	139.0	151.9	153.8
15	1	143.9	156.0	157.8
16	1	148.3	159.7	161.4
17	1	152.4	163.0	164.6
18	1	156.1	166.0	167.4
19	1	159.5	168.6	170.0
20	1	162.7	170.9	172.2
21	1	165.5	173.0	174.2
22	1	168.2	174.9	176.0
23	1	170.6	176.6	177.5
24	2	172.8	178.1	178.9
25	2	174.8	179.4	180.2
26	2	176.6	180.6	181.3
27	2	178.3	181.6	182.2
28	2	179.9	182.6	183.1
29	2	181.3	183.4	183.9
30	2	182.6	184.2	184.6
31	2	183.8	184.8	185.2
32	2	184.9	185.4	185.7
33	2	185.9	186.0	186.2
34	2	186.8	186.4	186.6
35	2	187.7	186.9	187.0
36	3	188.4	187.2	187.3

From the estimates of monthly growth curve by Gulland and Holt, Munro's and Fabens, the male crabs attained a size (carapace width) of 157.5, 156.1 and 159.1 mm by the completion of 1st year, 2nd year they reached a size of 190.6, 185.2 & 188.6 mm and 3rd year 197.5, 190.6 and 193.8 mm respectively. The same VBGF methods in females recorded a size of 128.0,142.0 & 144.1 in 1st year, 172.8, 178.1 and 178.9 mm in 2nd year and 188.4, 187.2 & 187.3 in 3rd year respectively (Tables 2.1 and 2.2).

DISCUSSION

In our country at present we do not have any organized fishery with strict management regulations for the blue swimmer crab, eventhough the market demand is raising. A regular fishery exists at few places at Palk Bay and Gulf of Mannar along the southeast coast and Mangalore area in West Coast. Bulk of the catch landed is by trawlers as a non-targeted by catch for crabs. Earlier at Mandapam region the *nanduvalai* catches were more as the total number of trawlers operated were comparatively less.

Prasad and Tampi (1951) described the *nanduvalai* fishery for catching *Neptunus pelagicus* near Mandapam. Even after four decades this traditional gear is still in operation in this region with some minor modifications. By 1970's trawl fishing also started for *P. pelagicus*, evident from the reports of Ameer Hamsa (1978b). In Karnataka *P. pelagicus* landed in trawlnets, minitrawl, shore seines, *Jebbubale* and *Kanthabale* (Sukumaran and Neelakantan, 1996c). The methods employed for crab fishing in the various estuaries and backwaters of India were almost similar (Jones and Sujansingani, 1952; Thomas, 1971; Rao *et al.* 1973; Prasad and Neelakantan 1989; Kurup *et al.* 1990).

At Mangalore, fishing was extended from September to late May or early June (Sukumaran and Neelakantan, 1996c). The occurrence of *P. pelagicus* from Vembanad lake was reported by Rao and Kathirvel (1971) during November to June, while Kurup *et al.* (1990) found that it started appearance only from January and extended upto June. In Zuary estuary, the presence of *P. pelagicus* was reported from December to April (Dhawan et *al.* 1976) and in Chilka Lake the season was

June-July to January (Jones and Sujansingani, 1952). In contrast to these observations, *P. pelagicus* is fished throughout the year both in trawl nets and gill nets at Mandapam area. During the present study, it was difficult to assume the peak-fishing season, as the maximum total catch was recorded in different months in all the centres.

Although several workers described the fishery and fishing methods for different species of crabs, very few reports are available on *P. pelagicus* fishery which dealt with total landings. Only Ameer Hamsa (1978b) has given an estimated average annual catch of Mandapam area. He has reported an average annual landing 246 tons for the period 1972-74. But during that period Vedalai was one of the most productive landing centres for *P. pelagicus*, now it is not an important landing centre. Moreover he has not given separate landings for each station, the data is not comparable. The annual CPUE for 1972-74 at Mandapam varied between 2.01-6.03 kg and Devipattinam between 13.37 and 15.28 kg. In the present study, these values were in a range of 3.4-4.8 kg and 7.7-23.4 kg respectively for the two centres. In Karnataka, *P. pelagicus* stands as the second important crab, next to *P. sanguinolentus*. Mangalore was the most productive centre for *P. pelagicus* with an annual average catch of 97.1 tonnes (Sukumaran and Neelakantan, 1996c) and CPH 0.25 kg. At Mandapam *P. pelagicus* was the single crab species landed, the annual average CPH was 0.324 kg during the study period.

Mandapam (Palk Bay) was the major contributor for *P. pelagicus* and the average annual catch for the three-year period was 167.5 t. Devipattinam occupied the second position with an average annual landing of 36.1 t followed by Mandapam (Gulf of Mannar), 10 t and Thoppukadu, 5.7 t. The fishery contributed by size groups ranging from 70-195 mm. Ameer Hamsa (1978b) has reported it as 60-209 mm. During the present study, it was never recorded a size above 195 mm carapace width. He also noted that the maximum size of male and female was 209 and 204 mm respectively whereas in the present study the maximum size for male and female was 195 and 193 mm respectively. Rao *et al.* (1973) reported a maximum size of 180 mm (CW), without mentioning the sex. From Australian waters Brown (1997) observed a maximum size of 195 mm for male and 180 mm for female (CW).

Stephenson and Campbell (1959) mentioned the size range of male and female crabs of *Portunus* genus *ie*. 9-185 mm in males and 18-170 mm in females. Hence, Ameer Hamsa's report still stands as a record size for *P. pelagicus*. It can be inferred that due to the intensified trawler operations than in the earlier period, these crabs may not be getting chance to grow larger before they caught in trawl nets.

Along the west coast in Karnataka, *P. pelagicus* juveniles (< 80 mm CW) are constituted upto 25 % in shrimp trawls and 71% in indigenous gears (Sukumaran and Neelakantan, 1996c). It is obvious that young crabs form the bulk of the catch in indigenous gear; the indigenous gear – *nanduvalai* – catches of Mandapam area included only very few crabs below 80 mm CW. In Kerala too, the crabs are caught from the very young size. Kurup *et al.* (1990) reported the size composition of *P. pelagicus* at Vembanad lake, was in the range of 48-161 mm, showed that fishery of the Mandapam region composed of comparatively bigger size groups.

Ameer Hamsa (1978b) reported that berried crabs were always more in trawl catches than in the gill nets. This is in conformity with the present study. *P. pelagicus* is a continuous breeder and berried crabs were caught in trawl nets throughout the year. But in *nanduvalai* in some months berried crabs were not at all observed and percentage was less even if they were present. Large mature females migrate offshore to spawn (Sumpton *et al.*, 1989) and this also explains the large proportion of ovigerous females sampled offshore. Campbell and Fielder (1986) have reported more than 50% of the catch of adult females as being ovigerous during most of summer and autumn. In the present study, in many months the same observation could be made. Wenner (1972) also found an increasing proportion of female *P. sanguinolentus* – a closely related species – with increasing depth in Hawaiian waters.

Eventhough *P. pelagicus* is a continuous breeder the percentage of maximum berried females in the catches were not at all followed a definite pattern over seasons during the three-year period of observation. However, many authors have reported breeding season for *P. pelagicus* as September-March (Prasad and Tampi, 1951), February-March (Dhawan *et al.*, 1976), January-March and September-December (Ameer Hamsa, 1978b) and September-April (Thompson, 1951) in Australian waters.

In this study the present exploitation rate in males and females is very close *i.e.* 0.54 and 0.52 respectively. As this values are very close to the E-max level (males-0.6382; females – 0.6481) and well above the 50% exploitation level (males-0.3712; females – 0.3788). Since the current yield of exploitation in males and females are close to the MSY level, it will be advantageous if the effort is maintained at the current level itself to obtain biologically optimum yield.

In the present study L_{max} recorded in the male crab was 195 mm and 193 mm in females. From the three VBGF approaches except Gulland and Holt $L\infty$ values are found to be less than the observed size. In females it is more obvious and $L\infty$ value of the latter two methods are even less than 193 mm. From the Gulland and Holt growth curve it is found that in the 3rd year male and female attain a carapace width of 197.5 mm and 188.4 mm. Hence it is reasonable to assume that the life span of these crabs may be around 3 years, although majority of the crabs fished out by intensive trawling in the early part of their life (0-year class), leaving only a few to attain their maximum age.

The trend of catches of *P. pelagicus* at the Mandapam area in the present study shows that the species is available for exploitation in the shallow coastal areas and adjacent deeper waters, throughout the year. From the observations on the size composition of the catches, it is obvious that in *nanduvalai* catches major portion of the crabs caught are immature, female crabs not even getting a single chance to breed in their lifetime. In trawl nets too the crabs are exploited rather indiscriminately, percentage of immature crabs are less compared to the *nanduvalai* but in some months fifty percent of the female population comprises berried crabs. The *P. pelagicus* catch data of recent years at Mandapam (Palk Bay) indicates a declining trend. At present there is no minimum-size regulation for crabbing in India. Whereas, in Australian waters (Thompson, 1951) only 6 inch size onwards are legally permitted to catch. The same size seems to be ideal in our country, since the female crabs by then get minimum 2-3 spawning cycles before their exploitation. At present, there is no ban for fishing berried crabs, since *P. pelagicus* is a continuous breeder and berried females are being exploited throughout the year. Fishermen must be given awareness and should be trained to throw back berried crabs to the sea while they are

alive, until minimum size fishing regulation comes into practice. A small percentage of soft crabs that are caught in nets should be released back to sea while alive. Government should take steps to implement ban during peak spawning seasons to prevent their indiscriminate fishing. But the best method to ensure a sustainable fishery throughout the year as well as to improve the quality of the yield, complete ban on fishing of berried crabs and their marketing is proposed.

In this context, it is noteworthy to recall here the history and development of blue swimmer crab fishery in Australia. *P. pelagicus* has been used as a resource gap filler, when alternate species are not available in the fishery (Campbell and Broderick, 1997). Since 1970's the fishery has developed from what was a highly seasonal non-target fishery, into what today is a fishery reaching final stages of recognition as a specialist fishery with its own specific scheme of management regulations (Mc Donald, 1997). There are separate licenses for trawl, Pot, gill net and recreational fisheries and fishermen have to follow strict management rules. In India too, it is necessary to implement such management strategies for the sustainable fishery of blue swimmer crabs.

CHAPTER III

CHAPTER III
BIOLOGY

INTRODUCTION

Relatively little is known about the life history of the blue swimmer crab, *Portunus pelagicus* (Linnaeus). Knowledge of the distinguishing characters and size relations of sexually mature individuals is of particular importance in the study of commercially important crustaceans. Such knowledge will be useful for further studies on the life history of the species and help in the development of its fishery, resource management and culture. The length-weight relationship, besides providing a mathematical relationship, also yields information on the general well-being, variation in growth with sex, size at first maturity, gonadal development and breeding season. The interrelationship between different morphometric characters viz. carapace width/length and chelar propodus length/depth in males and carapace width/length and abdomen width/ length in females is done and presented. It will be useful in comparing the different stocks of same species of different geographical locations.

Among the Indian workers Patel *et al.* (1979), Lalitha Devi (1985), Reeby *et al.* (1990a,b), Jacob *et al.* (1990) and Sukumaran and Neelakantan (1996a,1997a,b) studied the different biological aspects of *Portunus pelagicus* like length-weight relationship, maturity and breeding, food and feeding, and age and growth from the natural waters.

MATERIALS AND METHODS

Fortnightly random samples of 60-100 specimens from each of the sampling stations were taken for biological studies. Measurements were made for carapace width, carapace length and total weight sexwise. In addition to this, width and length of the abdomen were recorded for females and chelar (propodus) length and depth were taken for males. A vernier calliper with an accuracy of 0.5 mm was used for length measurements and weight of the whole crab was determined nearest to the possible gram (1 gm).

Carapace width (CW) is the distance between the tips of the last lateral spines.

Carapace length (CL) was measured dorsally along the middle line between the frontal notch and posterior margin of the carapace. Right chelar propodus length (Ch L) was measured from the tip of the propodus's fixed finger to the base of the propodus. Propodus depth (Ch D) of the same chela was measured across the widest region of the cheliped palm. When right chela is missing or damaged left chelar propodus length and depth were taken. Abdominal width was measured across the middle ventrally where the crab had maximum width *i.e.* fifth segment. Abdominal length was measured along the midline from the anterior margin of the first segment to the posterior margin of the last segment (Fig.3.1).

To study the interrelations between different morphometric characters in males, carapace length was regressed on chelar propodus length and chelar propodus depth; carapace width was regressed on chelar propodus length and chelar propodus depth and chelar propodus length was regressed on chelar propodus depth. In females carapace width and length were regressed on abdominal length and width and abdominal width was regressed on abdominal length.

Regression equations were calculated assuming an allometric growth equation ($Y = a + b$), to find out relations between different morphometric characters in males and females. The correlation coefficient (r) values were calculated to know the pattern of association between propodus / abdomen and carapace dimensions (Snedecor and Cochran, 1967), with the objective to establish a mathematical relationship between the variables, so that if one is known, the other could be computed approximately.

Estimation of carapace width - weight relationship

Carapace width-weight relationship was estimated using the log form of allometric growth equation $W = aL^b$, where W = expected weight, L = total carapace width and 'a' and 'b' are constants calculated by least square method. The differences in carapace width-weight relationship between sexes were tested by ANOVA using suitable computer programme.

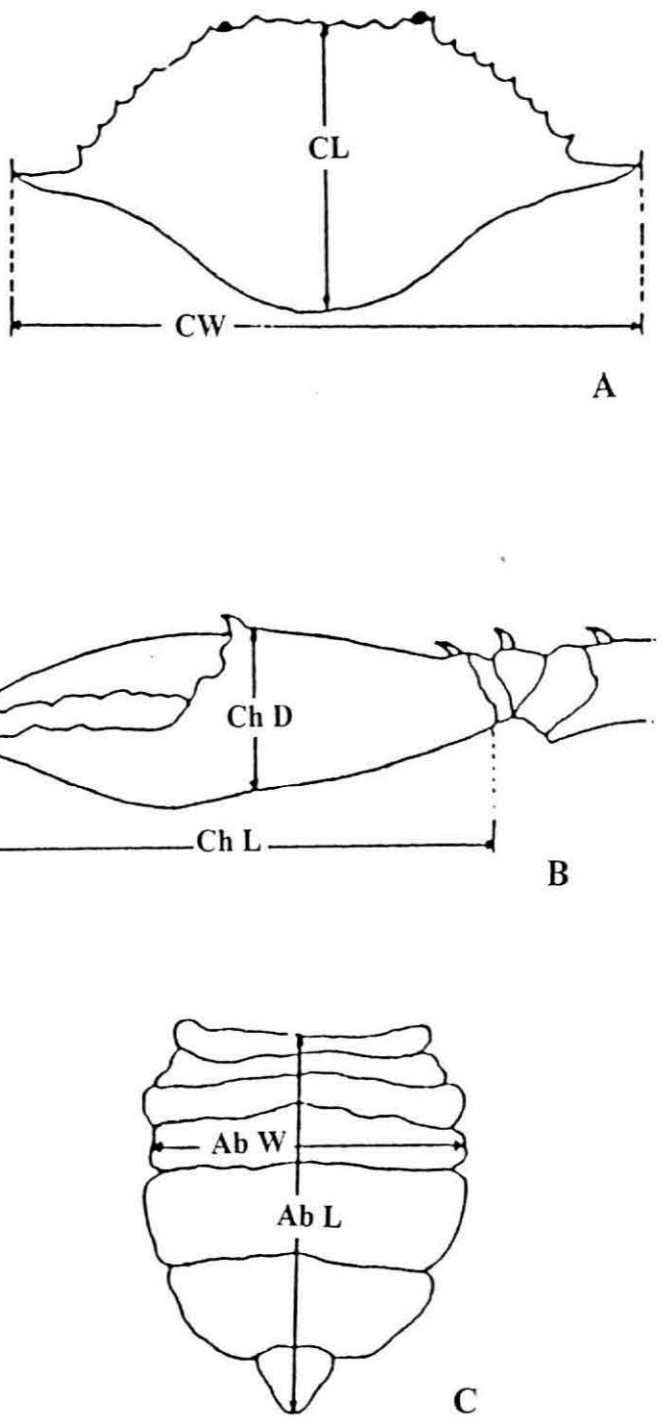


Fig. 3.1. The measurements used for morphometric studies in *Portunus pelagicus*.
A- Carapace dorsal view; **B**- Chela; **C**- Abdomen.
CW-Carapace width; **CL**-Carapace length; **Ch L**-Chelar propodus length; **Ch D**-Chelar propodus depth; **AbW**- Width of abdomen; **Ab L**- Length of abdomen.

Sex Ratio

Sex ratio was found out in all centres monthwise and sizewise. Their chi-square values were worked out to test whether they significantly differ from the 1:1 ratio (Snedecor and Cochran, 1967).

Study of reproductive biology

Crabs were sexed based on morphological differences. Male and female reproductive systems were studied by dissecting crabs of different size groups and observed under the dissection microscope and described. The ovaries and testes were classified into different maturity stages by modifying the methods suggested by Jacob *et al.* (1990) and Reeby *et al.* (1990a).

Gonado somatic index

GSI was calculated for a number of crabs belonging to different size groups using the formula,

$$\frac{\text{Weight of the ovary} \times 100}{\text{Total body weight}}$$

In the field, by visual examinations females were categorized into five stages of maturity (In the commercial landings it was noticed, a substantial percentage of females were infected with the parasite *Sacculina* sp. In such cases gonadial development was arrested. This category of females was grouped as 'parasite infected' crabs and stage as V). The stages are as follows:

Stage I.	Immature with closed /tight abdomen.
Stage II.	Mature crabs with open abdomen but not in berried condition
Stage III.	Pleopods carrying egg mass with yellow/orange colour.
Stage IV.	Pleopods with deep grey coloured egg mass.
Stage V.	Parasite infected crabs.

Fecundity

Fecundity of the crab was calculated by counting the number of eggs deposited on the pleopods of the ovigerous females. Forty-one crabs from different size groups were used for fecundity studies. Egg masses from each crab were carefully removed from the pleopods and weighed accurately using electronic balance

(Adair Dutt, Calcutta; model - 0.001g). A 0.1g sample was taken from each egg mass, smeared and dispersed in seawater and were counted through binocular compound microscope. The total number of eggs counted in the sample was then computed. Occular micrometer (ERMA, Japan) calibrated with stage micrometer was used to take micrometric measurements of eggs in different stages of development. Correlation coefficient (r) was used to determine the fecundity relationship (Snedecor and Cochran, 1967).

The relationship between carapace width (CW) and egg mass weight/fecundity; crab weight and egg mass weight/fecundity; egg mass weight and fecundity were determined by regression analysis. Egg mass index was determined using the formula:

$$\text{Egg mass index} = \frac{\text{Mean egg mass weight} \times 100}{\text{Mean crab weight}}$$

Parasitisation

All the specimens collected from the sampling centres were examined to find out the percentage of parasite infected crabs month wise.

Food and feeding studies

Studies on food and feeding were carried out, adapting Sukumaran (1995). For food and feeding studies, *P. pelagicus were* collected once a month from the commercial catches of shrimp trawlers during the year 1997. After recording the carapace width, length and total weight, the dorsal side of the body was cut open and the foregut was removed carefully and the fullness of stomach was visually examined and assessed as 0, 25, 50, 75 and 100 %. The foreguts were preserved in 10% formalin for a week and cut open and its contents were transferred into petridishes with water. The food components were separated and identified under a binocular microscope.

As characteristic of brachyurans, most of the food items were found to be unidentifiably highly crushed form and hence only the hard structures that could be identified were relied upon for food composition and evaluation. The gut contents were broadly classified into five categories as follows:

1. Crustacean remains - penaeid shrimp appendages, crab body parts and eggs; isopod and stomatopod parts.
2. Fish remains - fins, scales, bones and vertebrae.
3. Molluscan remains - bivalves and gastropods.
4. Miscellaneous-algal filaments, nematodes, polychaetes and unidentified items.
5. Debris - sand and mud.

The quantity and food components in males and females were not significantly different from one another and hence the food data for both sexes were combined. Stomachs with food only were considered for calculation.

Specimenwise, the whole stomach content was segregated food-groupwise and each group's contribution determined visually. Domination of food groups was evaluated by ranking them by its percentage frequency of occurrence and percentage points. Percentage frequency of occurrence was estimated as:

$$\frac{\text{No. of stomachs with particular food group} \times 100}{\text{No. of stomachs with food.}}$$

To estimate the volume of the food groupwise, points were assigned to each group as suggested by Stehlik (1993). To quote one, a food group which formed 50% of the total food content of a stomach which was 50% full was assigned 25 points (50points x 0.50). Percentage points were estimated as:

$$\frac{\text{Point of the particular food group} \times 100}{\text{Total points of all food groups}}$$

RESULTS

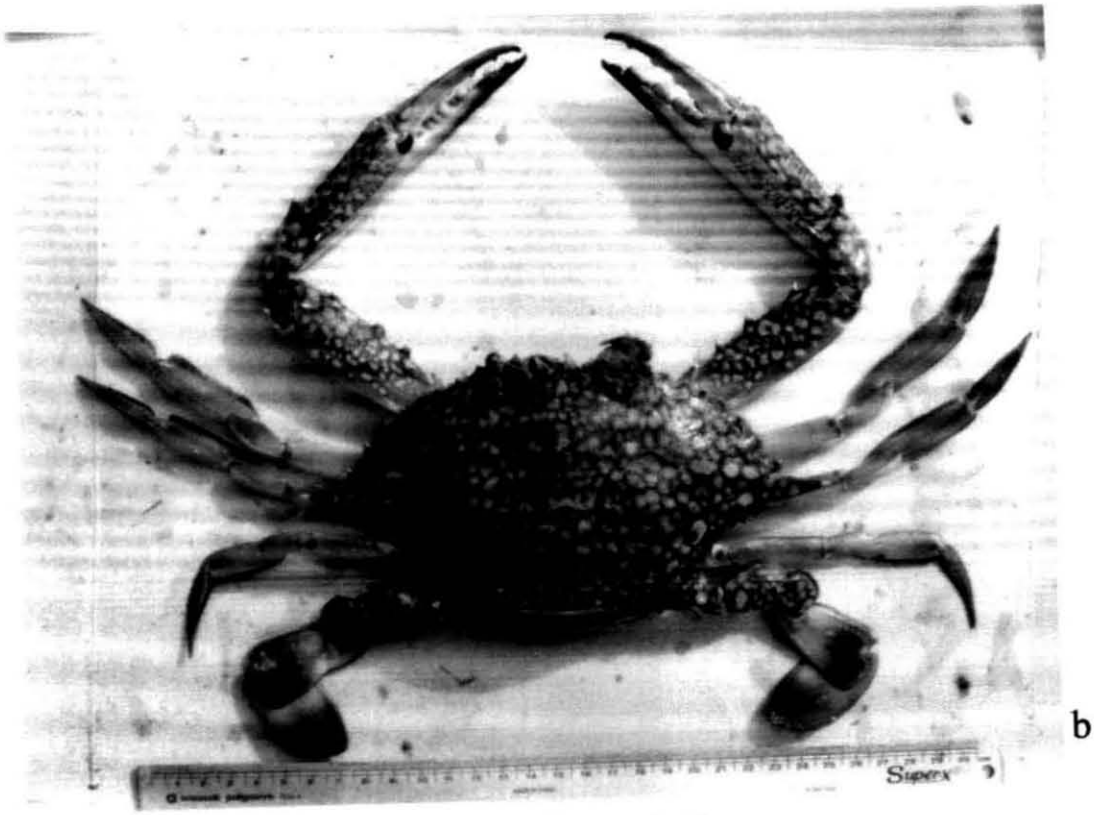
Sexuality

In *Portunus pelagicus*, sexes can be easily differentiated from their colour patterns of dorsal exoskeleton. Males are brightly coloured and more attractive than females. The carapace of the male crab is brilliantly coloured with irregular white patches and the tips of chelate and walking legs bright blue, hence the name 'blue swimmer crab'. But female crabs are dull brown in colour with small irregular white patches on the carapace and tips of chelate and walking legs dark brown (Plate 6.a,b).

Other sexual dimorphic characters in *P. pelagicus* are similar to that of other

Plate 6

a



b

a. Adult male - Dorsal view
b. Adult female - Dorsal view

crabs. Sex is readily distinguished in larger individuals by the shape of the abdomen which is narrow and has the shape of inverted 'T' in males, while that of female, it is triangular in juveniles and changes to semicircular in adult. In addition, male has a relatively larger chela than female. Male has pleopods modified as copulatory organs on the first and second abdominal somites. In the case of females the first four abdominal somites carry pleopods, and are biramous and possess setae for attachment of the extruded eggs till hatching (Plate 7.a,b).

Interrelationship between different morphometric characters

Allometric equations with respect to males and females are indicated in the following tables. The allometric relation between the set of characters studied suggested that in most cases the relationship was positive and highly significant (Fig 3.2 to 3.11).

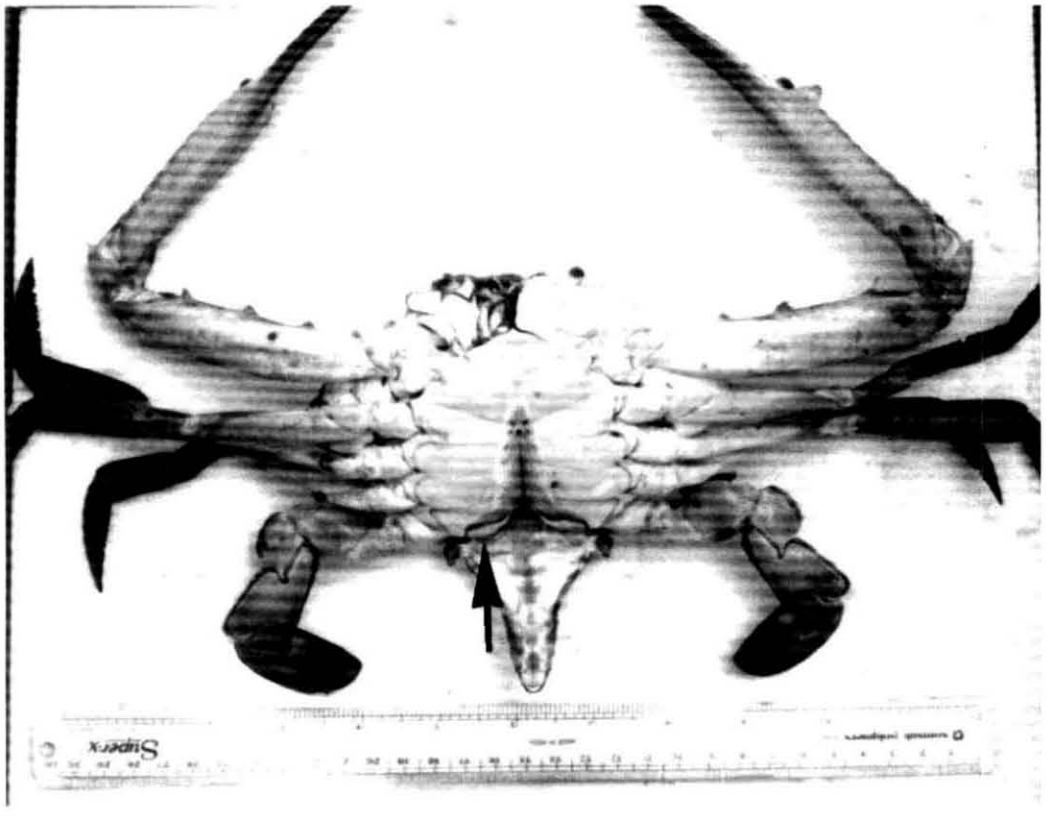
Males

Independent variable (X)	Dependent variable (Y)	Allometric growth equation (Y = a + bx)	'r^2' Value
Carapace Width	Chelar Propodus Length	CPL = -65.085+ 1.2079 CW	0.9249
Carapace Width	Chelar Propodus Depth	CPD = -1.8734+ 0.1547 CW	0.3016
Carapace Length	Chelar Propodus Length	CPL = -47.378 + 2.4352 CL	0.9316
Carapace Length	Chelar Propodus Depth	CPD = -0.2268 + 0.3227 CL	0.3142
Chelar Propodus Length	Chelar Propodus Depth	CPD = 6.7359+ 0.1255 CPL	0.3055

Females

Independent variable (X)	Dependent variable (Y)	Allometric growth equation (Y = a + bx)	'r^2' Value
Carapace Width	Abdomen width	AW = -21.058 + 0.4806 CW	0.8651
Carapace Width	Abdomen Length	AL = -13.511 + 0.4433 CW	0.8755
Carapace Length	Abdomen width	AW = -14.274 + 0.9828 CL	0.8573
Carapace Length	Abdomen Length	AL = -7.8259 + 0.9139 CL	0.8675
Abdomen Width	Abdomen Length	AL = -4.9636 + 1.0550 AW	0.9128

Plate 7

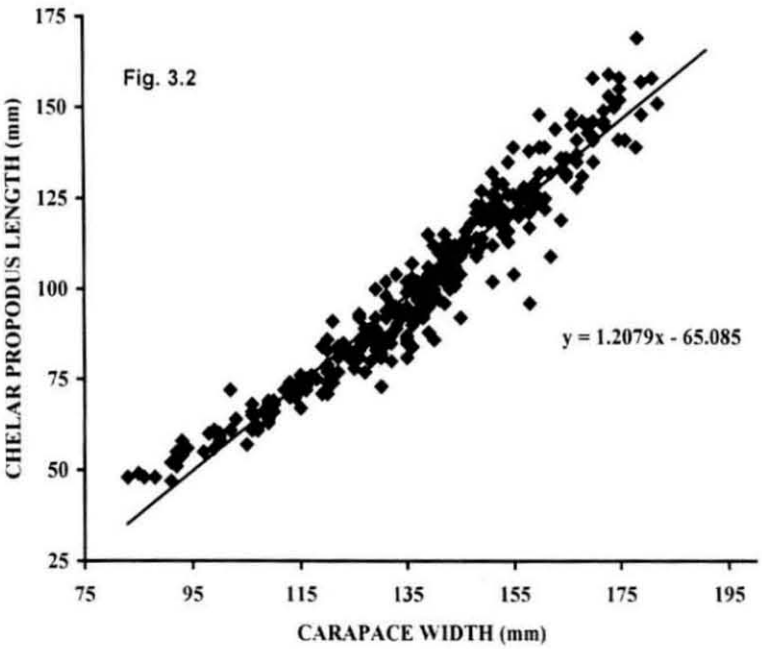


a

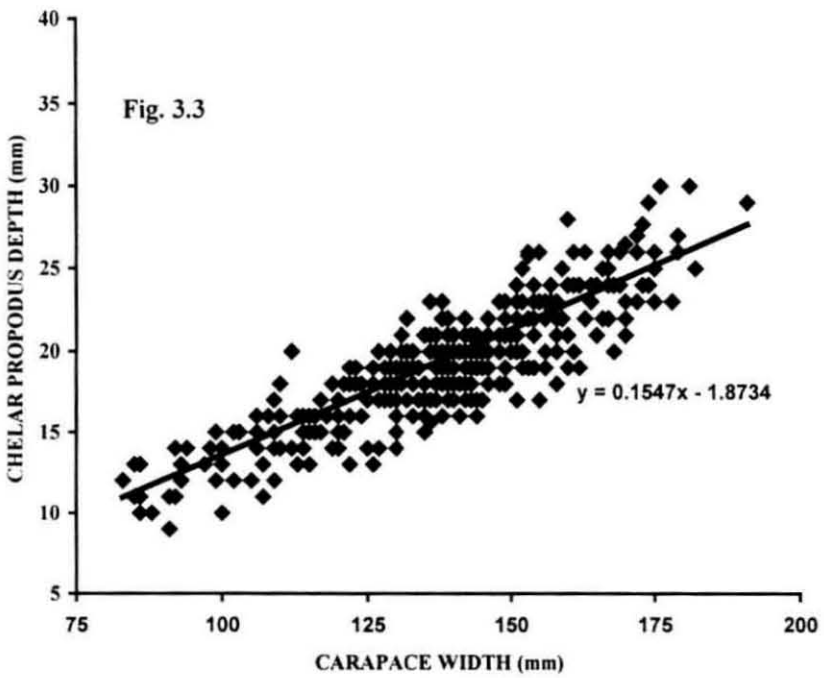
b

Adult male (a) and female (b) crabs with open abdomen showing position and arrangements of pleopods.

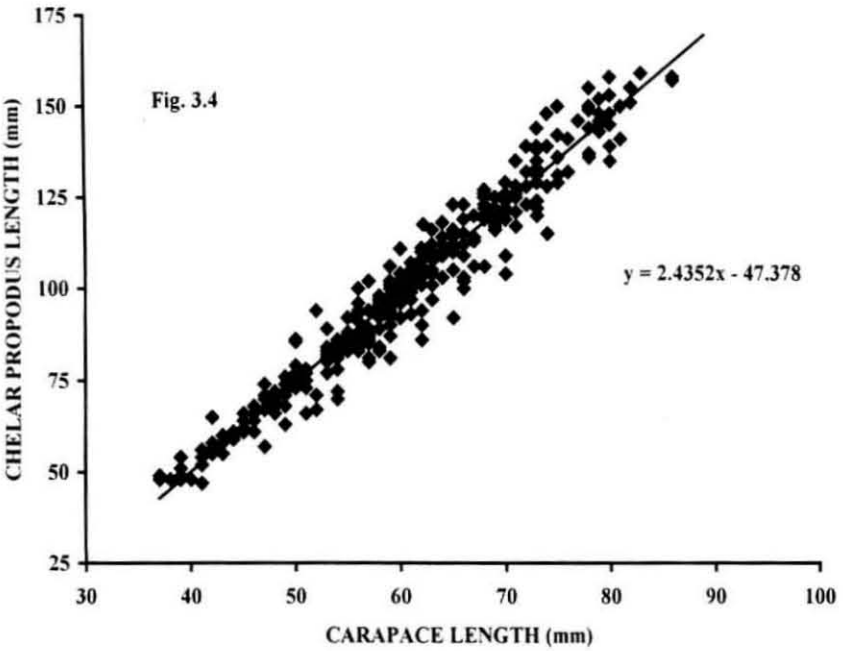
CARAPACE WIDTH AND CHELAR PROPODUS LENGTH
RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES)



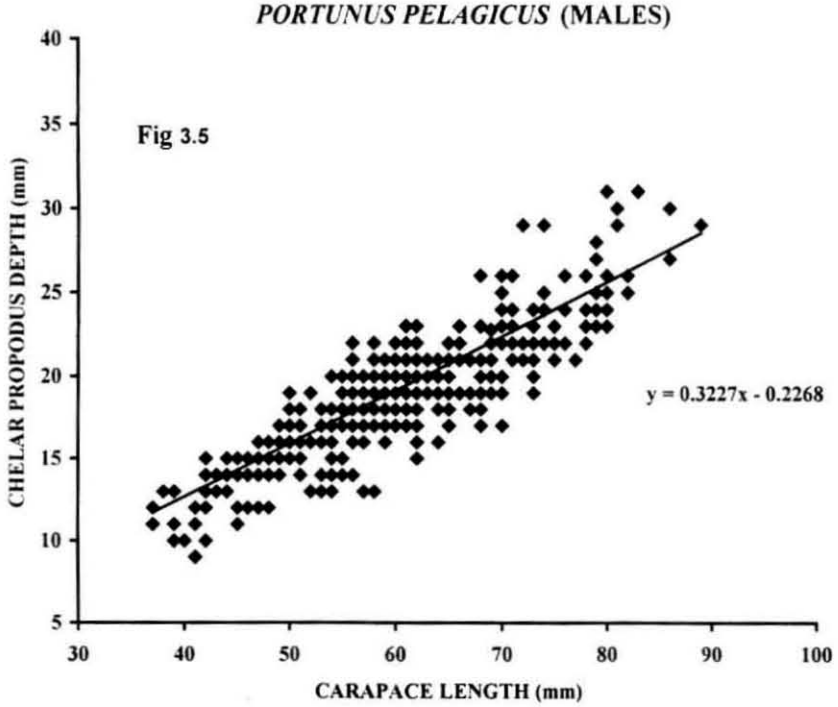
CARAPACE WIDTH AND CHELAR PROPODUS DEPTH
RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES)



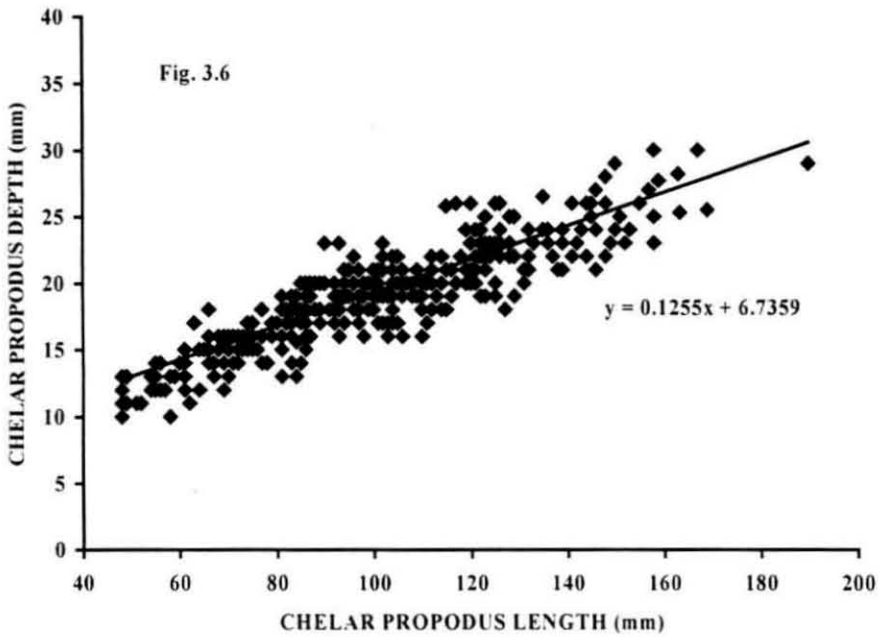
CARAPACE LENGTH AND CHELAR PROPODUS
LENGTH RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES)



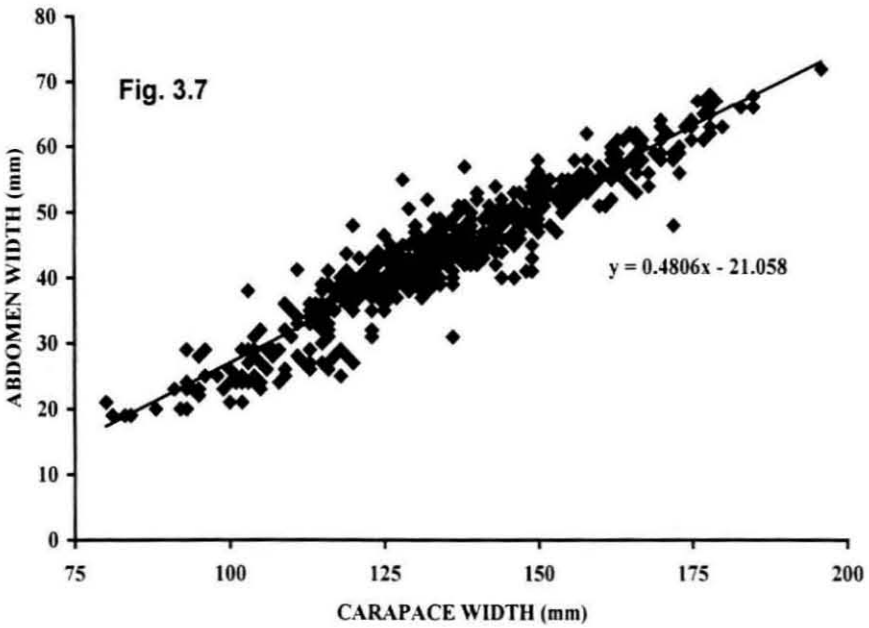
CARAPACE LENGTH AND CHELAR PROPODUS
DEPTH RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES)



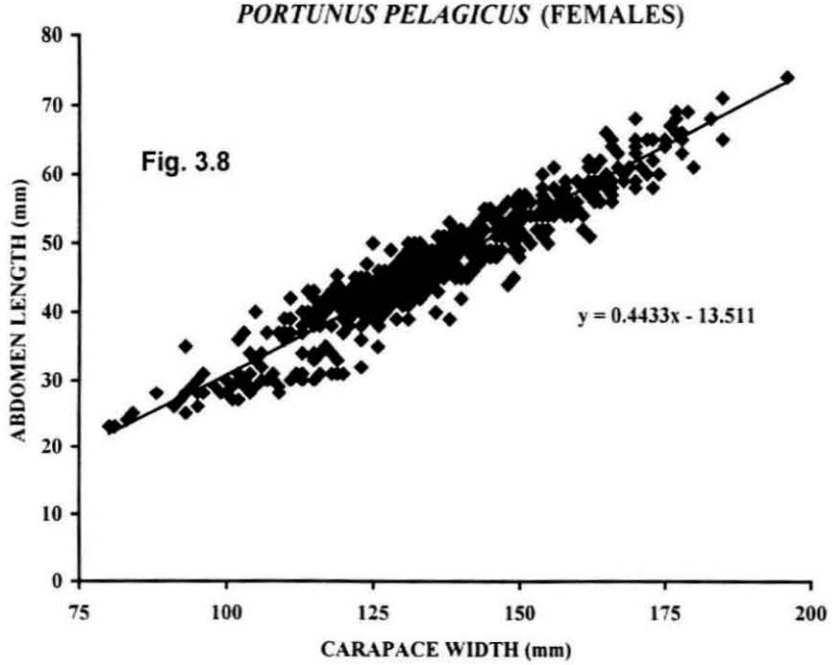
CHELAR PROPODUS LENGTH AND CHELAR PROPODUS DEPTH RELATIONSHIP IN *PORTUNUS PELAGICUS* (MALES)



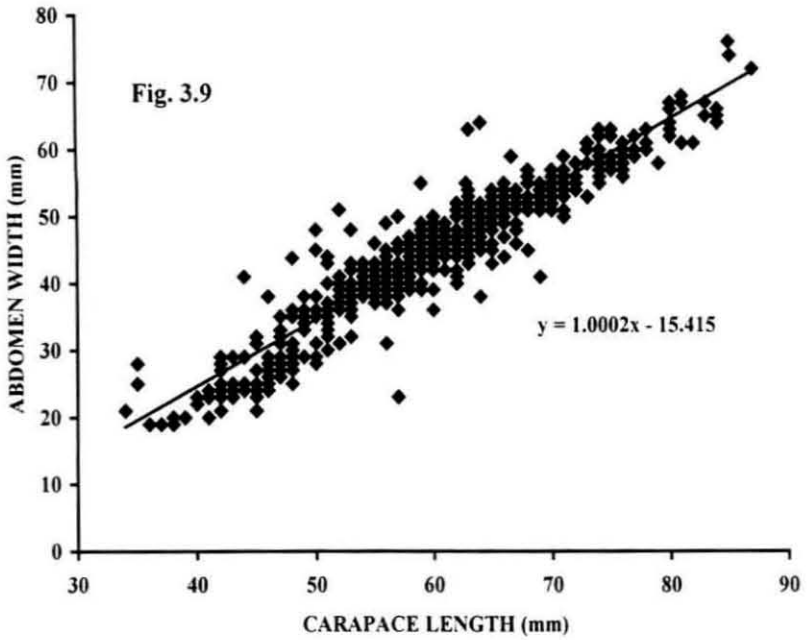
CARAPACE WIDTH AND ABDOMEN WIDTH
RELATIONSHIP IN
PORTUNUS PELAGICUS (FEMALES)



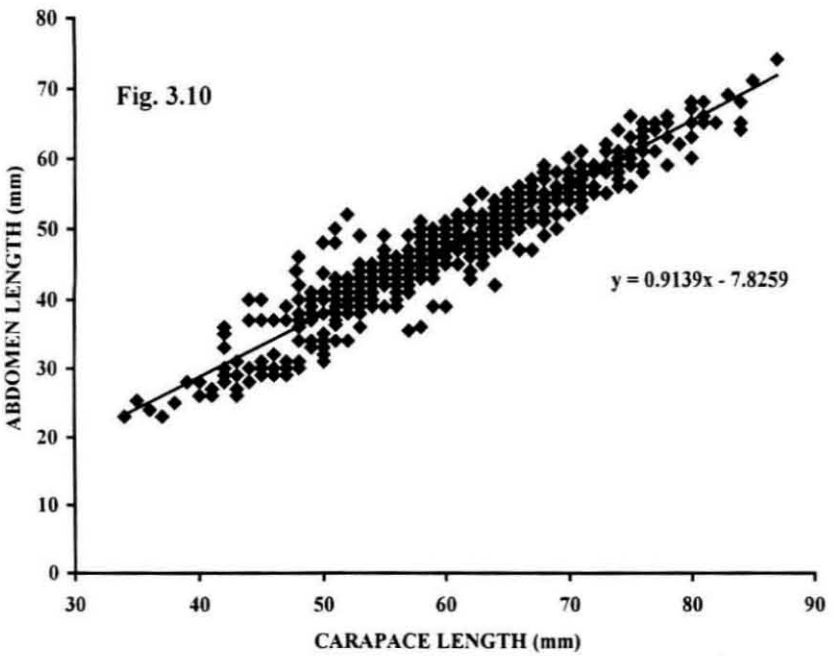
CARAPACE WIDTH AND ABDOMEN LENGTH
RELATIONSHIP IN
PORTUNUS PELAGICUS (FEMALES)



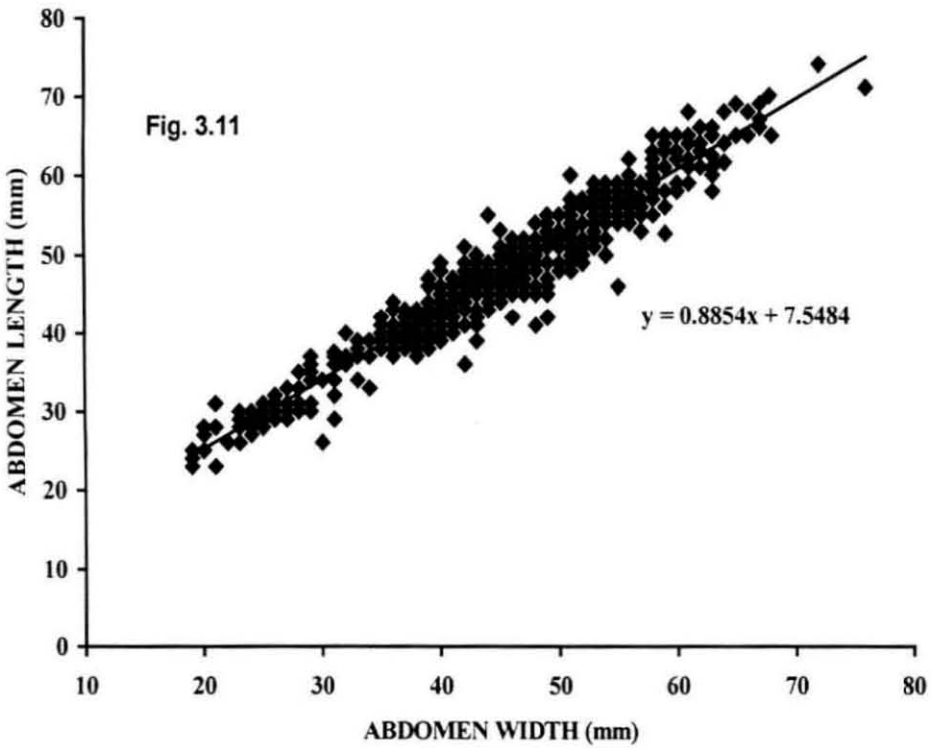
CARAPACE LENGTH AND ABDOMEN WIDTH RELATIONSHIP IN *PORTUNUS PELAGICUS* (FEMALES)



CARAPACE LENGTH AND ABDOMEN LENGTH RELATIONSHIP IN *PORTUNUS PELAGICUS* (FEMALES)



ABDOMEN WIDTH AND ABDOMEN LENGTH RELATIONSHIP IN *PORTUNUS PELAGICUS* (FEMALES)



Carapace width and total weight relationship

The study has shown that females are marginally heavier than males till 120-125 mm carapace width and thereafter males heavier than females. The results are given in the following table.

Measurements	Logarithmic equation	Parabolic equation
Male		
Carapace Width-Total Weight	Log = -12.589 + 3.607 log L	$W = 0.000003409L^{3.607}$
Carapace Length-Total Weight	Log = -7.339 + 3.049 log L	$W = 0.0006497\ L^{3.049}$
Female		
Carapace Width-Total Weight	Log = -11.077 + 3.293 log L	$W = 0.00001546\ L^{3.293}$
Carapace Length-Total Weight	Log = -6.231 + 2.774 log L	$W = 0.001967\ L^{2.774}$
Pooled		
Carapace Width-Total Weight	Log = -11.779 + 3.438 log L	$W = 0.000007664L^{3.438}$
Carapace Length-Total Weight	Log = -6.746 + 2.902 log L	$W = 0.001176\ L^{2.902}$

The scatter diagram for males and females was obtained by plotting the weight against carapace width /length of individual crabs (Fig.3.12 to 3.15). It is found that there exists a good relation between width and total weight from the closeness of the scatter and parabolic nature of the plot.

The exponential values (b) for the carapace width-weight relationship in males and females (3.607 and 3.293 respectively) show that there is marked variation from the isometric pattern of growth. The 't' test confirmed that 'b' significantly differ from 3, in both sexes. The exponential values (b) for carapace length – weight in males and females (3.049 and 2.774 respectively) indicate that, the significant departure from isometric growth is only evident in females. In males it followed isometric growth pattern. The 't'values are given in the following table.

CARAPACE WIDTH - WEIGHT RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES)

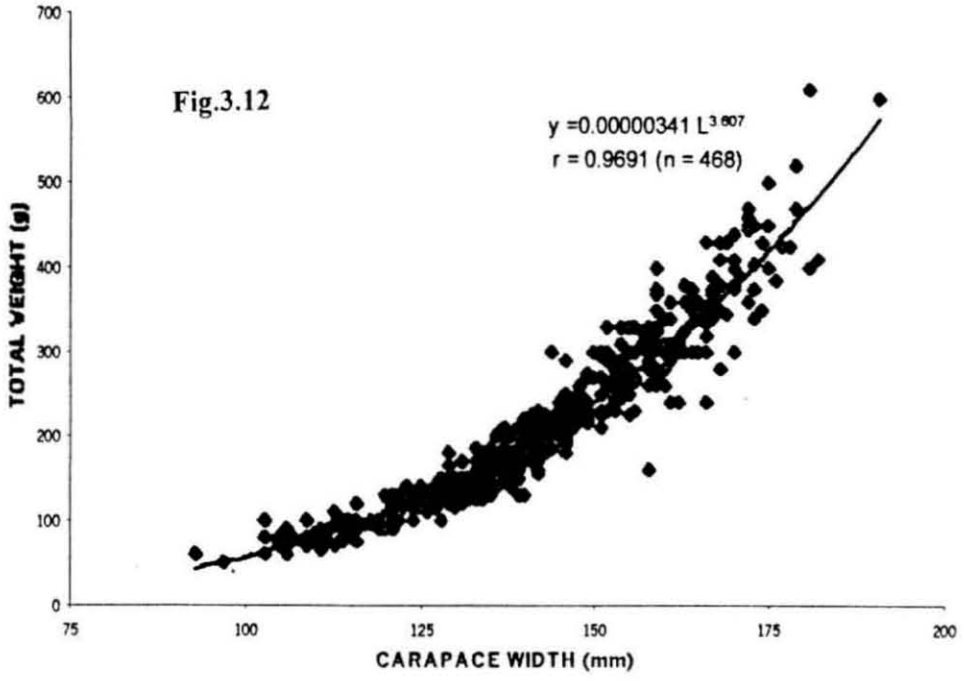


Fig.3.12

CARAPACE LENGTH- WEIGHT RELATIONSHIP IN
PORTUNUS PELAGICUS (MALES).

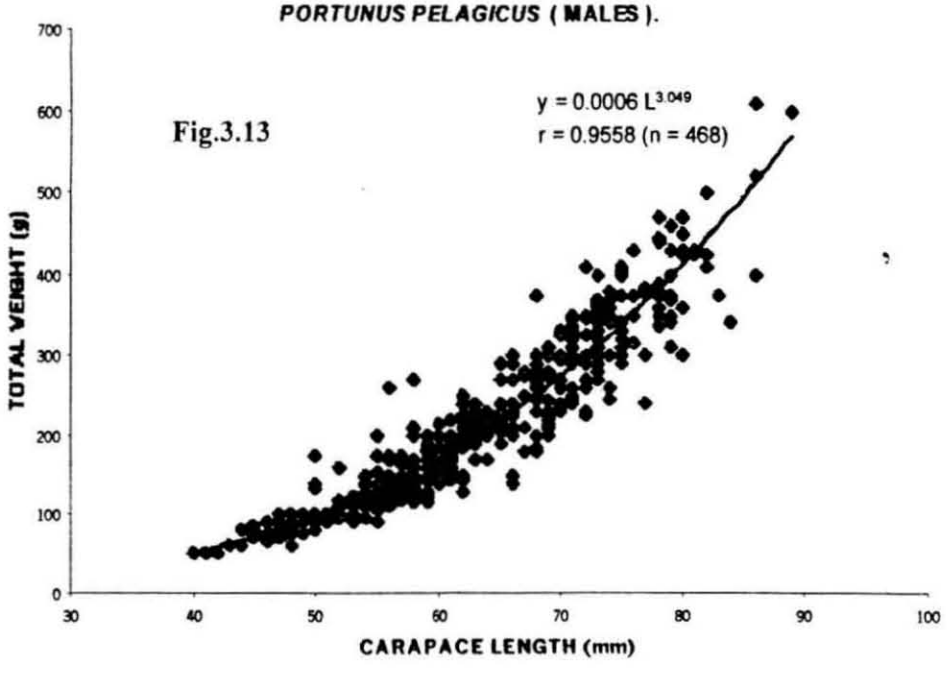
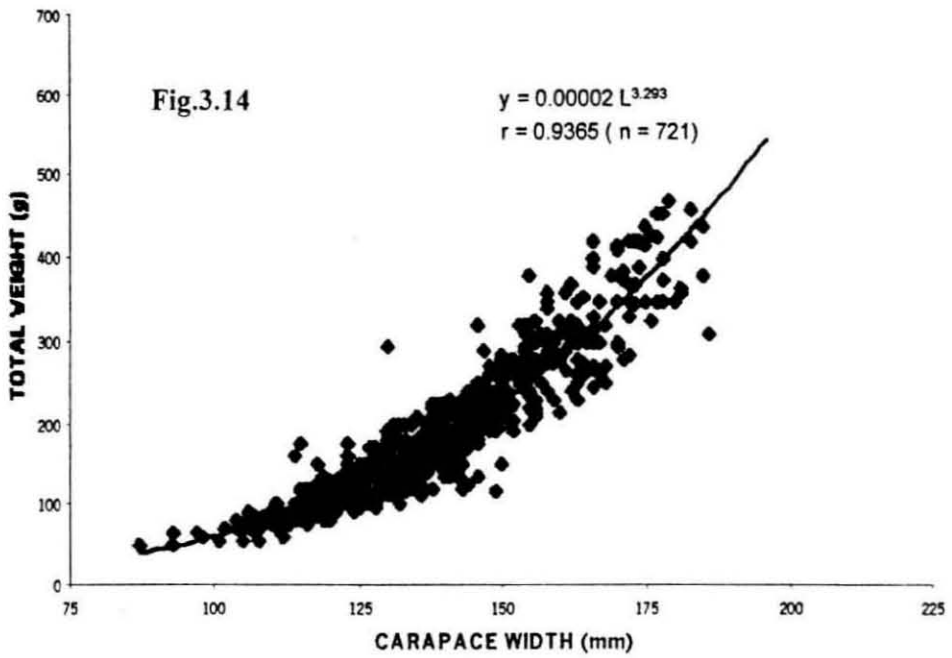
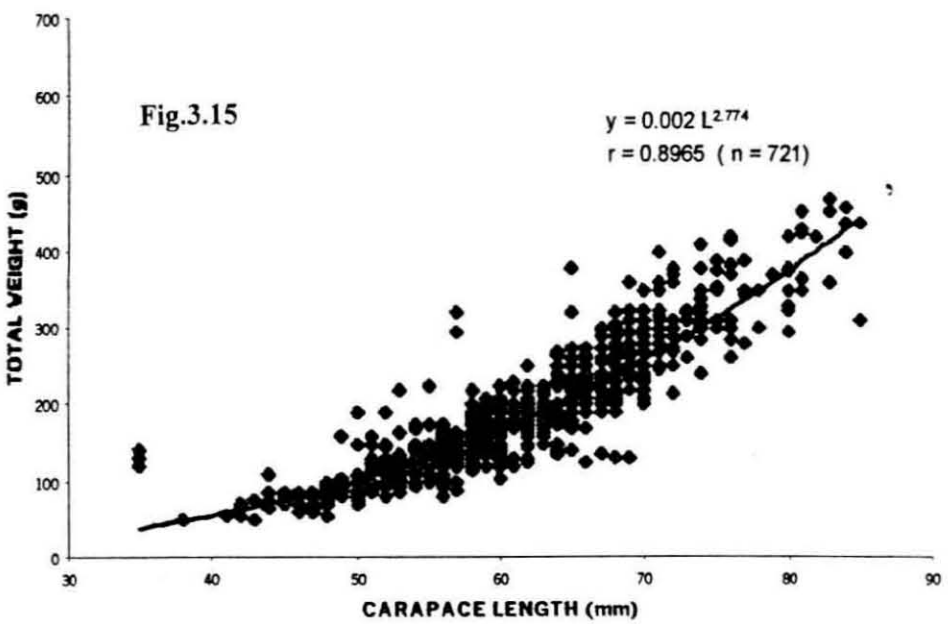


Fig.3.13

CARAPACE WIDTH - WEIGHT RELATIONSHIP IN
PORTUNUS PELAGICUS (FEMALES).



CARAPACE LENGTH - WEIGHT RELATIONSHIP IN
PORTUNUS PELAGICUS (FEMALES)



Relationship	Sex	't' Value	Remarks
CW-TW	Male	14.29	Significant at 1% level
CW-TW	Female	6.39	Significant at 1% level
CL-TW	Male	1.29	Not significant
CL-TW	Female	4.42	Significant at 1% level

The results of analysis of covariance are presented in the tables 3.1 and 3.2. From the table it is observed that difference between slopes ($F=23.15$; $P < 0.01$) and the difference between elevations ($F=17.09$; $P<0.01$) were highly significant, indicating that there is significant difference between the sexes in respect of the carapace width-weight relationship. In the case of carapace length-weight relationship also it was significant (between slopes $F= 15.28$; $P <0.01$) and between deviations ($F=3.93$; $P <0.05$).

Sex ratio

In trawl catches at Mandapam (Palk Bay and Gulf of Mannar) females were dominating the catches during most of the months. Whereas in *nanduvalai* catches at Devipattinam, females were dominating in all the sampling months during 1995 and for the rest of the period males were dominating in most of the months. At Thoppukadu, males were dominating the catch in almost all the months throughout the period. Month wise and size wise sex ratio and chi-square values for all the centers are given in the Tables 3.3 to 3.10.

At Mandapam females outnumbered the males, the male: female ratio was 0.72: 1 with marginal variations during different months of the study period. At Gulf of Mannar side it was 0.9: 1 with variations similar to Palk Bay. Devipattinam and Thoppukadu showed preponderance of males, the sex ratio was 1.13: 1 and 1.26: 1 respectively. The chi-square values (month wise) for the pooled data at four centers were significant and given in the following table.

Centre	Sample size	Sex ratio (%)	Sex ratio (M/F)	Chi-squre value	Remarks
Mandapam-Palk Bay	2478	41.93 :58.07	0.72	64.58	S
Gulf of Mannar	417	47.24 :52.76	0.90	1.27	NS
Devipattinam	1906	52.90 :47.10	1.13	6.58	S
Thoppukkadu	1351	55.80 :44.20	1.26	9.12	S
Pooled	6152	48.75 :51.25	0.95	3.9	S

Table 3.1 ANOVA Table for testing the equality of regression lines in the Carapace width- Total weight relationship among males and females of *Portunus pelagicus*

RESOURCE	D.F	SS	MS	F
Deviation from individual Regression (within sexes)	1188	25.546	0.02150	
Difference between regressions	1	0.489	0.48862	23.15**
Deviation from average Regression	1187	25.057	0.02110	
Differences between Corrected means	1	0.367	0.36748	17.09**

** Significant at 1% level

Table 3.2. ANOVA table for testing the equality of regression lines in the Carapace length- Total weight relationship among males and females of *Portunus pelagicus*

SOURCE	DF	SS	MS	F
Deviation from individual Regression (within sexes)	1188	39.202	0.033	
Difference between regressions	1	0.498	0.49839	15.28 **
Deviation from average Regression	1187	38.704	0.03261	
Differences between Corrected means	1	0.13	0.12955	3.93*

** Significant at 1 % level ; * Significant at 5% level.

Table. 3.3. MONTHWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT MANDAPAM (PALK BAY).

MONTH	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
1995					
JULY	42	45.2:54.8	0.83	0.38	NS
AUGUST	49	44.9:55.1	0.81	0.51	NS
SEPTEMBER	64	45.3:54.7	0.83	0.56	NS
OCTOBER	29	55.2:44.8	1.23	0.31	NS
NOVEMBER	32	46.9:53.1	0.88	0.13	NS
DECEMBER	29	41.4:58.6	0.71	0.86	NS
1996					
JANUARY	29	44.8:55.2	0.81	0.31	NS
FEBRUARY	33	45.5:54.5	0.83	0.27	NS
MARCH	63	47.6:52.4	0.91	0.14	NS
APRIL	32	59.4:40.6	1.46	2.25	NS
MAY	29	41.4:58.6	0.71	0.31	NS
JUNE	38	42.1:57.9	0.73	1.90	NS
JULY	36	38.9:61.1	0.64	1.80	NS
AUGUST	128	40.6:59.4	0.68	4.50	S
SEPTEMBER	139	41.7:58.3	0.72	3.22	NS
OCTOBER	169	45.9:54.1	0.86	1.00	NS
NOVEMBER	126	40.5:59.5	0.68	4.57	S
DECEMBER	124	43.5:56.5	0.77	2.06	NS
1997					
JANUARY	188	47.9:52.1	0.92	0.34	NS
FEBRUARY	156	44.2:55.8	0.79	2.08	NS
MARCH	122	41.0:59.0	0.69	3.97	S
APRIL	118	44.9:55.1	0.82	1.22	NS
MAY	130	29.2:70.8	0.41	22.40	S
JUNE	129	30.2:69.8	0.43	20.16	S
JULY	100	30.0:70.0	0.43	16.00	S
AUGUST	82	24.4:75.6	0.32	21.51	S
SEPTEMBER	-	-	-	-	
OCTOBER	80	43.8:56.2	0.78	1.25	NS
NOVEMBER	102	48.0:52.0	0.92	0.16	NS
DECEMBER	80	51.3:48.7	1.05	0.05	NS
POOLED	2478	41.9:58.1	0.72	64.57	S

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.4. MONTHWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT MANDAPAM (GULF OF MANNAR).

MONTH	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
1996-97					
OCTOBER	63	42.86:57.14	0.75	1.29	NS
NOVEMBER					
DECEMBER	33	45.45:54.55	0.83	0.27	NS
JANUARY	43	41.86:58.14	0.72	1.14	NS
FEBRUARY	18	55.56:44.44	1.25	0.22	NS
MARCH	45	44.44:55.56	0.80	0.56	NS
1997-98					
OCTOBER	26	57.70:42.30	1.36	0.62	NS
NOVEMBER	39	48.72:51.28	0.95	0.03	NS
DECEMBER	35	48.57:51.43	0.94	0.03	NS
JANUARY	38	42.11:57.89	0.73	0.95	NS
FEBRUARY	35	48.57:51.43	0.94	0.03	NS
MARCH	42	54.76:45.24	1.21	0.38	NS
POOLED	417	47.24:52.76	0.90	1.27	NS

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.5. MONTHWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT DEVIPATTINAM

MONTH	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
1995					
JULY	18	38.9:61.1	0.66	0.89	NS
AUGUST	56	44.6:55.4	0.81	0.64	NS
SEPTEMBER	73	49.3:50.7	0.97	0.01	NS
OCTOBER	36	50.0:50.0	1.00	0.00	NS
NOVEMBER	39	46.2:53.8	0.86	0.23	NS
DECEMBER	-	-	-	-	-
1996					
JANUARY	26	65.4:34.6	1.89	2.46	NS
FEBRUARY	32	50.0:50.0	1.00	0.00	NS
MARCH	30	46.7:53.3	0.88	0.13	NS
APRIL	35	57.1:42.9	1.33	0.71	NS
MAY	25	68.0:32.0	2.13	3.24	NS
JUNE	28	50.0:50.0	1.00	0.00	NS
JULY	71	45.1:54.9	0.82	0.69	NS
AUGUST	101	45.5:54.5	0.84	0.80	NS
SEPTEMBER	121	50.4:49.6	1.01	0.01	NS
OCTOBER	90	48.9:51.1	0.96	0.44	NS
NOVEMBER	102	55.9:44.1	1.27	1.41	NS
DECEMBER	78	56.4:43.6	1.29	1.28	NS
1997					
JANUARY	86	60.5:39.5	1.53	3.77	NS
FEBRUARY	95	53.7:46.3	1.16	0.52	NS
MARCH	100	55.0:45.0	1.22	1.00	NS
APRIL	85	55.3:44.7	1.24	1.42	NS
MAY	94	54.3:45.7	1.19	0.68	NS
JUNE	91	53.8:46.2	1.17	0.54	NS
JULY	92	52.2:47.8	1.09	0.17	NS
AUGUST	97	50.5:49.5	1.02	0.01	NS
SEPTEMBER	43	67.4:32.6	2.07	5.23	S
OCTOBER	45	57.8:42.2	1.37	1.09	NS
NOVEMBER	72	56.9:43.1	1.32	1.39	NS
DECEMBER	45	55.6:44.4	1.25	0.56	NS
POOLED	1906	52.9:47.1	1.13	6.58	S

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.6. MONTHWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT THOPPUKKADU

MONTH	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
1995					
JULY	25	56.0:44.0	1.27	0.36	NS
AUGUST	17	47.1:52.9	0.88	0.06	NS
SEPTEMBER	44	59.1:40.9	1.44	1.45	NS
OCTOBER	21	52.4:47.6	1.10	0.05	NS
NOVEMBER	53	50.9:49.1	1.04	0.02	NS
DECEMBER	27	59.3:40.7	1.45	0.93	NS
1996					
JANUARY	19	57.9:42.1	1.38	0.47	NS
FEBRUARY	-	-	-	-	-
MARCH	20	65.0:35.0	1.86	1.80	NS
APRIL	21	71.4:28.6	2.50	3.90	S
MAY	23	52.2:47.8	1.09	0.04	NS
JUNE	60	51.7:48.3	1.07	0.07	NS
JULY	52	63.5:36.5	1.74	3.80	NS
AUGUST	-	-	-	-	-
SEPTEMBER	19	57.9:42.1	1.38	0.47	NS
OCTOBER	78	56.4:43.6	1.29	1.28	NS
NOVEMBER	47	57.4:42.6	1.35	1.04	NS
DECEMBER	59	61.0:39.0	1.57	2.90	NS
1997					
JANUARY	83	56.6:43.4	1.31	1.46	NS
FEBRUARY	37	73.0:27.0	2.70	7.81	-
MARCH	77	53.2:46.8	1.14	0.32	NS
APRIL	95	60.0:40.0	1.50	3.80	NS
MAY	102	50.0:50.0	1.00	0.00	NS
JUNE	52	46.2:53.8	0.86	0.31	NS
JULY	47	51.1:48.9	1.04	0.02	NS
AUGUST	89	50.6:49.4	1.02	0.01	NS
SEPTEMBER	12	66.7:33.3	2.00	1.30	S
OCTOBER	59	57.6:42.4	1.36	1.37	NS
NOVEMBER	49	59.2:40.8	1.45	1.65	NS
DECEMBER	64	50.0:50.0	1.00	0.00	NS
POOLED	1351	55.8:44.2	1.26	18.23	S

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.7. SIZEWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT MANDAPAM (PALK BAY).

SIZE GROUP (mm)	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
71-80	3	33.3:66.7	0.50	0.33	NS
81-90	10	20.0:80.0	0.25	3.60	NS
91-100	46	41.3:58.7	0.70	1.39	NS
101-110	170	61.2:38.8	1.58	8.49	S
111-120	253	43.1:56.9	0.76	4.84	S
121-130	423	35.5:64.5	1.04	35.77	S
131-140	537	37.4:62.6	0.60	33.94	S
141-150	431	40.8:59.2	0.69	14.48	S
151-160	312	49.4:50.6	0.97	0.21	NS
161-170	200	51.5:48.5	1.13	0.18	NS
171-180	104	50.9:49.1	1.04	0.04	NS
181-190	35	42.9:57.1	0.75	0.71	NS
191-200	4	50.0:50.0	1.00	0.00	NS

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.8. .SIZEWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT MANDAPAM (GULF OF MANNAR).

SIZE GROUP (mm)	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
81-90	11	45.45:54.55	0.83	0.10	NS
91-100	40	47.50:52.50	0.90	0.10	NS
101-110	53	45.28:54.72	0.83	0.47	NS
111-120	52	42.31:57.69	0.73	1.23	NS
121-130	76	42.11:57.89	0.73	1.89	NS
131-140	59	49.20:58.80	0.97	0.02	NS
141-150	51	50.98:49.02	1.04	0.02	NS
151-160	41	56.10:43.90	1.28	0.61	NS
161-170	16	68.75:31.25	2.20	2.25	NS
171-180	8	62.50:37.50	1.67	0.50	NS

S - Significant at 5% level ; NS - Not significant at 5% level.

Table. 3.9.SIZEWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT DEVIPATTINAM.

SIZE GROUP (mm)	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
71-80	1	00.0:100.0	-	1.00	NS
81-90	27	25.9:74.1	0.35	6.26	S
91-100	88	31.8:68.2	0.46	11.64	S
101-110	267	46.1:53.9	0.85	1.65	NS
111-120	405	57.3:42.7	1.34	8.60	S
121-130	528	57.9:42.1	1.38	13.36	S
131-140	382	59.7:40.3	1.48	14.34	S
141-150	151	44.4:55.6	0.80	1.91	NS
151-160	52	36.5:63.5	0.56	3.77	NS
161-170	9	22.2:77.8	0.30	2.78	NS
171-180	4	100.0:00.0	-	4.00	S
181-190	2	100.0:00.0	-	2.00	NS

S - Significant at 5% level ; NS - Not significant at 5% level.

Table.3.10. SIZEWISE CHI-SQUARE ANALYSIS OF SEX RATIO IN *PORTUNUS PELAGICUS* AT THOPPUKKADU.

SIZE GROUP (mm)	SAMPLE SIZE	SEX RATIO (%)	SEX RATIO (M/F)	CHI-SQUARE VALUE	REMARKS
81-90	14	57.1:42.9	1.33	0.29	NS
91-100	81	45.7:54.3	0.84	0.60	NS
101-110	283	55.5:44.5	1.23	3.40	NS
111-120	353	57.5:42.5	1.35	7.96	S
121-130	335	57.0:43.0	1.33	6.59	S
131-140	203	52.7:47.3	1.11	0.60	NS
141-150	69	56.5:43.5	1.30	1.17	NS
151-160	8	87.5:12.5	7.00	4.50	S

S- Significant at 5% level ; NS- Not significant at 5% level.

Study of reproductive biology

Male reproductive system : The male reproductive organ is bilateral and is consists of a paired testes, vas deferentia, ejaculatory duct and external penis (Fig. 3.16). The first and secondary abdominal appendages are highly modified to function as copulatory organ.

Testes: As in the gonads of most decapod crustacea, the paired testes in *P. pelagicus* are medially interconnected by a commissure and they approximate the shape of the alphabet 'H'. In immature crabs the testes are rather inconspicuous and is difficult to make out on dissection. Mature testis has the appearance of slender white convoluted tube. It is sandwitched between the hypodermis of carapace and hepatopancreas. The organ is opaque with irregular surface and the distal portion on either side is bent along the antereo-lateral border of carapace.

Vas deferens: It has got three distinct regions, Anterior vas deferens (AVD), Median vas deferens (MVD) and Posterior vas deferens (PVD). The AVD consists of white tightly coiled tubes, lying on either side of the median line of cephalothorax. The AVD of each side rests on the respective MVD. The anterior most coils are slender transluscent and delicate and bound together by a thin but strong membrane and cannot be separated or straightened by dissection. The coils increase in size posterioventrally and lead into MVD, which is the most massive part of the system. PVD is massive in its proximal part, but it gradually narrows before opening into the ejaculatory duct.

Ejaculatory duct: Arises behind the PVD as a narrow tube passes through the musculature of the fifth walking leg and opens at the coxal segment through the penis.

Penis: The penis is a slender weak tube, which arises from the ventromedian border of the coxopodite of the fifth pereiopod. The gonoduct can be seen as a white opaque tube at the centre.

Pleopod 1 & 2: The first pair of pleopod is larger than the second and it may serve as the functional intromittant organ. In related species of portunids it is reported that the first pleopod receives spermatophores and sperms from the small penis and act as a tube of transport in copulation, carrying these materials into the

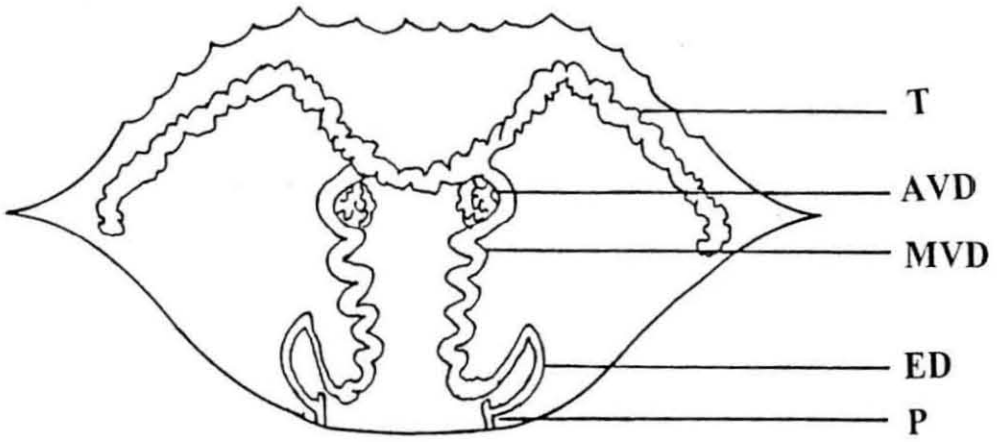


Fig. 3.16. Diagramatic sketch of Male reproductive system in *Portunus pelagicus*. T- Testis; AVD- Anterior vas deferens; MVD- Median vas deferens; ED- Ejaculatory duct; P- Penis.

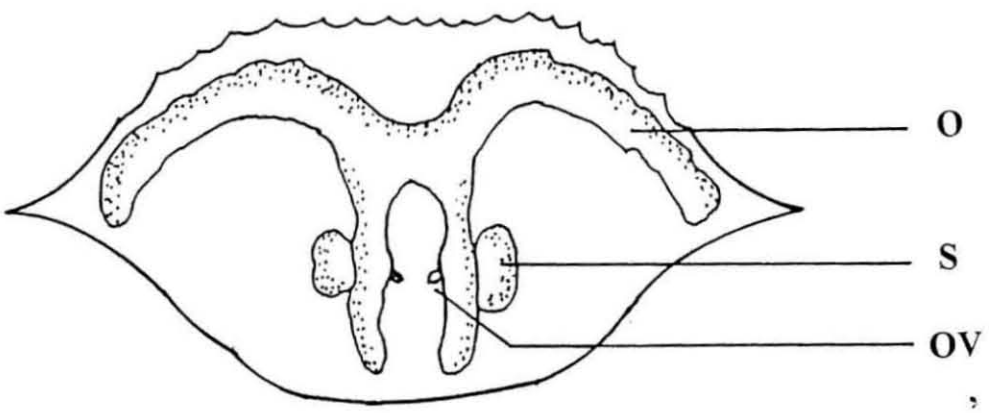


Fig. 3.17. Diagramatic sketch of Female reproductive system in *Portunus pelagicus*. O- Ovary; S- Spermatheca; OV- Oviduct.

paired vagina and the seminal receptacle of adult female. The second pleopod is inserted into the posterior foramen of the first pleopod and forces semen and spermatophores through the tube like intromittant flagellum of the first pleopod.

Female reproductive system

The ovary is 'H' shaped and located dorsally just beneath the carapace (Fig.3.17). The entire ovary is bound by a fibrous connective tissue, which serves to separate the organ from surrounding haemocoel. The horns of ovary extend anterolaterally from either side of the gastric mill and dorsal to the hepatopancreas; the anterior horns are joined by a commissure. The posterior horns, which lie ventral to the heart, extend posteriorly on either side of the intestine. The seminal receptacle arises from the mid-lateral border of the posterior horns actually an enlarged portion of the oviduct. Each seminal receptacle leads into a small circular gonopore (Vulva) situated on the sixth thoracic sternite.

During mating, the sperms are transferred to the seminal receptacle, which act as a storage organ. Viable sperms are utilized during subsequent spawnings of that particular intermoult period. As the eggs are laid, they adhere to one another and to the setae of the endopodites of the abdominal segment, and the maturing egg mass/ sponge is held between the reflexed abdomen and venter of the cephalothorax.

The abdominal chamber acts as an incubation chamber for the developing eggs. The newly spawned eggs are yellow in colour; as development progresses the colour changes to dull yellow and finally to deep grey just before hatching.

Females undergo more than one maturation moult, and consequently abdominal shape changes to semicircular. Hence from the shape of the abdomen it can be made out whether the eggs /sponge belong to the first maturation cycle or that of later stages.

Gonado-somatic index

The GSI values for different ovarian stages are shown in the following table.

Stage	Condition of the ovary	GSI range	% in the total sample
I	Thin, transparent, thread like ovary without prominent seminal receptacle (Immature).	0.32-1.10	31.25
II	Light yellow ovary with little peripheral undulations (Early maturing).	2.80-4.25	25.00
III	Bright yellow or orange coloured ovary extending into carapace (Late maturing).	8.95-12.85	27.08
IV	Bright orange or orange red coloured ovary with prominent seminal receptacle(Mature).	15.28-20.25	16.67

Size at maturity

Close laboratory examination of gonads indicated that males of *P. pelagicus* attained first sexual maturity when they attained a size above 80 mm carapace width. The minimum size at which males mature was 82 mm of carapace width. The percentage of maturity increased with the size (carapace width), reaching 100% in 130 mm and above. Out of the 153 crabs used for maturity studies 15.03% were immature, 22.9% were maturing and 62.1% were mature. The details are given in Table 3.11.

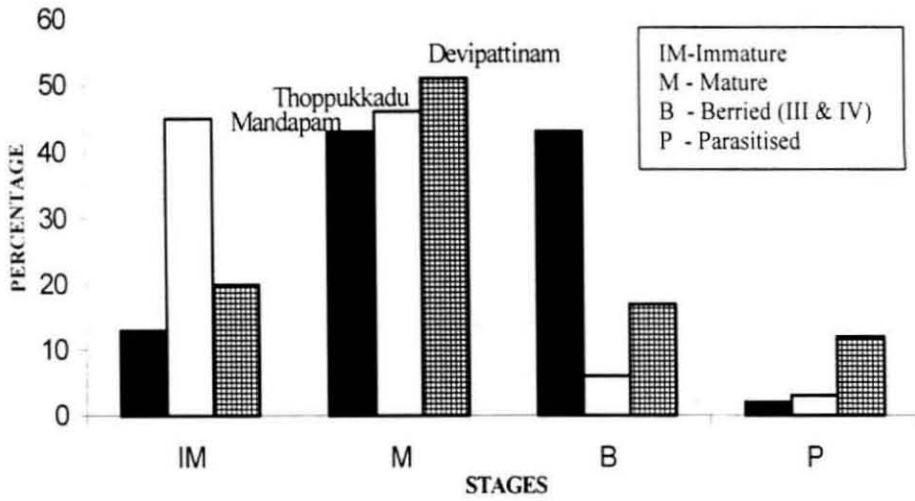
In females the minimum size at which maturity (ovary stage-IV) recorded was 88 mm (CW). In females, mature ovaries were very rare in those below 100 mm (CW) size. Among the crabs dissected for this study spent ones were very rare, hence not included in the total number. The sizewise details are given in the following Table.

Size group	I (%)	II (%)	III (%)	IV (%)	No. of crabs
81-100	60.80	21.74	13.04	4.35	23
101-120	28.57	33.33	26.19	11.90	42
121-140	30.76	15.38	23.08	30.76	13
141-160	0	12.50	50.00	37.50	8
161-180	0	20.00	50.00	30.00	10
TOTAL NO.	30	24	26	16	96

Table- 3.11 . PROPORTION OF DIFFERENT MATURITY STAGES IN MALES OF *PORTUNUS PELAGICUS*

	STAGE-1		STAGE-11		STAGE-111		
SIZE RANGE (mm)	IMMATURE	%	MATURING	%	MATURE	%	TOTAL
< 80	0	0	0	0	0	0	0
81-85	4	100	0	0	0	0	4
86-90	3	42.86	3	42.86	1	14.29	7
91-95	3	25	6	50	3	25	12
96-100	6	50	4	33.33	2	16.67	12
101-105	2	20	5	50	3	30	10
106-110	4	28.57	6	42.86	4	28.57	14
111-115	1	11.11	4	44.44	4	44.44	9
116-120			3	27.27	8	72.73	11
121-125			2	25	6	75	8
126-130			2	9.09	20	90.91	22
131-135					6	100	6
136-140					6	100	6
141-145					7	100	7
146-150					3	100	3
151-155					6	100	6
156-160					3	100	3
161-165					3	100	3
166-170					4	100	4
171-175					2	100	2
176-180					1	100	1
TOTAL	23	15.23	35	23.18	93	61.59	151

The minimum size of berried females encountered during the study was 105/ 80, 113/80, 113/90 and 105/90 (mm/g), from Mandapam (Palk Bay and Gulf of Mannar), Devipattinam and Thoppukadu respectively. Berried crabs were recorded in the landings throughout the year. Berried crabs were more in trawl catches; and in near-shore *nanduvalai* catches the percentage was very less and in some months berried females did not even represent the fishery. Out of the 2932 female crabs sampled from all the centres, 73.4% were mature and out of that, only 37.2% carried eggs in their pleopods (stage III & IV). Immature crab landings were 21.8 % and parasitised crabs 4.8%. The stationwise details are given in the following graph.



Fecundity

The number of eggs present in the sponge/berry in *P. pelagicus* ranged between 60000 and 1976398. The average number of eggs for the different classes is given in the following table.

Size range (mm)	No.	Carapace width (mm)	Average weight (g)	Egg mass weight (g)	Ave.tot. no. eggs	Egg mass index
100-109	2	104.7±0.78	87.5±3.54	13.96±1.2	203455	15.95
110-119	6	113.6±2.66	11.96±16.66	11.96±4.07	214175	11.39
120-129	12	124.9±2.93	124.2±19.87	20.84±5.54	640431	16.78
130-139	5	133.8±3.91	148.0±17.18	19.20±8.57	470092	12.97
140-149	4	144.8±3.54	210.0±60.14	28.37±12.00	936731	13.51
150-159	2	157.5±2.69	287.5±17.68	30.36±12.05	1267022	10.56
160-169	2	166.6±1.62	320.0±28.28	34.50±7.56	1230900	10.78
170-179	4	176.1±2.36	406.3±39.87	49.74±5.55	1472240	12.24
180-189	4	183.1±2.01	532.5±32.27	53.41±4.84	1677168	10.03

Fecundity was steadily increasing from lower to higher size groups. In the landings, it was found that the crabs, which belonged to size group 120-129 mm, were more, which coincided with first maturation moult. Egg mass index did not show any clear pattern in relation with the size groups of the crab. Egg mass weight increase was proportional to the carapace width of the crab, with highest value in higher size groups.

The statistical relationship between fecundity and egg mass weight in relation to carapace width and total weight suggested that significant positive correlation was observed in all relationships studied. Among them carapace width and fecundity were better indices for the estimation of the reproductive potential rather than the weight of the crab. It was seen that there was a direct relationship between fecundity and egg mass weight. The details are given in the following table.

Relationship	Exponential formula	r^2 Value
Carapace Width- Egg mass Weight	$Y = 1.5395\ e^{0.0194x}$	0.79572
Carapace Width-Fecundity	$Y = 12473\ e^{0.0278x}$	0.82523
Total Weight-Egg mass Weight	$Y = 11.474\ e^{0.0032x}$	0.79370
Total Weight-Fecundity	$Y = 233213\ e^{0.0044x}$	0.77662
Egg mass Weight-Fecundity	$Y = 164310\ e^{0.0484x}$	0.86376

Parasitisation

Among the 5768 no. of *P. pelagicus* sampled during 95-'97, 48.4% were males and the rest females. In females 5.4 % of crabs were parasitised with a rhizocephalan parasite *Sacculina* (plate 8).

In parasite infected crabs, the body of the sacculinid arise from the ventral surface of the abdomen and in such crabs, moult cycle could be interrupted. Internally the gonads are affected either indirectly or by the invasion of the organ by the roots of the parasite. There are considerable difficulties in the detection of rhizocephalans during its internal phase; so crabs with visible external parasite were taken into account. The parasite-infected crabs belong to smaller size groups and their size range varied from station to station. At Mandapam (Palk Bay) the sizes ranged between 91-140mm and at Devipattinam and Thoppukkadu between 71-140mm. The dominant size groups at Mandapam, Thoppukkadu and Devipattinam was 101-110mm, 91-100mm and 101-110mm respectively.The percentage of parasite infected crabs were more at Devipattinam and present in the catch throughout the year with two peaks; first during June- July and second in October-November. At Mandapam these crabs were reported maximum during October- November and absent in the catch in January, March and September. At Thoppukkadu, *Sacculina* infected crabs were absent during February, March, June, August and September and maximum observed in April. The details are given in the following table.

Months	Mandapam (%)	Thoppukkadu (%)	Devipattinam (%)
APRIL	0	28	8
MAY	8	11	9
JUNE	0	0	13
JULY	8	11	12
AUGUST	12	0	8
SEPTEMBER	0	0	6
OCTOBER	32	11	11
NOVEMBER	24	6	10
DECEMBER	4	11	7
JANUARY	0	22	5
FEBRUARY	8	0	5
MARCH	0	0	6

Plate 8

Parasite infected crab showing 'externa' in the abdomen

Epizoants such as barnacles were also seen attached over crab's exoskeleton. The frequency of barnacle encrustation was more in older crabs than on the younger ones and the latter is relatively free of any settling living organisms.

Food and feeding

The diet of *Portunus pelagicus* consisted mainly of crustaceans, molluscs, fishes, large quantity of unidentifiable matter and debris. Out of the 452 stomachs examined 3.54% were 100% full; 19.91% were 75% full; 25.66% were 50% full; 26.77% were 25% full and 24.1% were empty. The monthwise and sizewise details are given in the table 3.12 and 3.13.

Whenever food was found in the stomachs, it was mixed of food groups. On analysis it was found that the percentage of frequency of occurrence of miscellaneous items was 83.09% of the cases; Debris 79.59%; Crustaceans 78.43%; Molluscs 59.48% and Fishes 56.27% (Table 3.14).

The points of major food groups (size wise and month wise) are given in the tables 3.15 and 3.16. In percentage of points crustaceans was the most dominant food group and found in 28.57% of the stomachs 'with food' and consisted primarily of decapods (parts of shrimp rostrum, exoskeleton, appendages; crab exoskeleton, appendages and eggs), amphipods, isopods and stomatopods. In different size groups of crabs crustaceans remains varied between 6.5 and 28.9% .

The second dominant item of food was 'mollusc remains' mainly of bivalves and gastropods. It ranged between 8.6 and 16.7% in various size groups and its maximum percentage was observed in 101-120mm group. Fish remains formed the third important item of food. Fish remains were present in 15.42 % of the stomachs. The percentage points of 'fish remains' varied between 2.4 to 30.8 %. Fish food dominated in the stomachs of higher size groups of 141-160 and 161-180 mm.

The miscellaneous group mainly comprised of crushed polychaetes, plant materials of seaweed and sea grasses *etc*. This group was present in majority of the stomachs and varied between 19.2 to 42.5 %. The detritus was available in 18.96 % of stomachs. Their percentage of points in different size groups varied between 10.0 and 41.4%.

Table. 3.12.CONDITION OF STOMACH DURING VARIOUS MONTHS IN *PORTUNUS PELAGICUS*

NUMBER / % →	EMPTY	25%	50%	75%	FULL	TOTAL
MONTH ↓						
JAN.	01 (3.57)	11 (39.29)	12 (42.86)	04 (14.29)	0	28
FEB.	07 (15.56)	14 (31.11)	14 (31.11)	04 (8.89)	06 (13.33)	45
MAR.	11 (35.48)	09 (29.03)	03 (9.68)	07 (22.58)	01 (3.23)	31
APR.	06 (11.76)	16(31.37)	10 (19.61)	19 (37.25)	0	51
MAY	07 (43.75)	03 (18.75	04 (25.00)	02 (12.50)	0	16
JUN.	09 (21.43)	09 (21.43)	12 (28.57)	10 (23.81	02 (4.76)	42
JUL.	10 (22.73)	07 (15.91)	10 (22.73)	14 (31.82)	03 (6.82)	44
AUG.	05 (23.81)	03 (14.29)	09 (42.86)	03 (14.29(	01 (4.76)	21
SEP.	08 (22.22)	09 (25.00)	11 (30.56)	08 (22.22)	0	36
OCT.	15 (27.27)	17 (30.91)	17 (30.91)	06 (10.91)	0	55
NOV.	15 (38.46)	12 (30.77)	06 (15.38)	04 (10.26)	02 (5.13)	39
DEC.	15 (34.09)	11 (25.00)	08 (18.18)	09 (20.45)	01 (2.27)	44
TOTAL	109(24.12)	121(26.77)	116(25.66)	090(19.91)	016(3.54)	452

Table. 3.13. CONDITION OF STOMACH IN DIFFERENT SIZE GROUPS OF *PORTUNUS PELAGICUS*

NUMBER / % →	EMPTY	25%	50%	75%	FULL	TOTAL
SIZE CLASS ↓						
61-80	06 (40.00)	01 (6.67)	04 (26.67)	04 (26.67)	0	15
81-100	43 (31.62)	28 (20.59)	36 (26.47)	23 (16.91)	06 (4.41)	136
101-120	36 (21.43)	49 (29.17)	41 (24.40)	34 (20.24)	08 (4.76)	168
121-140	13 (18.06)	23 (31.94)	19 (26.39)	16 (22.22)	01 (1.39)	72
141-160	09 (19.57)	12 (26.09)	13 (28.26)	11 (23.91)	01 (2.17)	46
161-180	02 (13.33)	08 (53.33)	03 (20.00)	02 (13.33)	0	15
TOTAL	109	121	116	90	16	452

Table. 3.14. PERCENTAGE OF POINTS AND FREQUENCY OF OCCURRENCE OF MAJOR FOOD GROUPS IN *PORTUNUS PELAGICUS.*

ITEMS	POINTS	% OF POINTS	% OF FREQUENCY OF OCCURRENCE
CRUSTACEAN REMAINS	4844	28.57	78.43
MOLLUSCAN REMAINS	2761	16.28	59.48
FISH REMAINS	2614	15.42	56.27
MISCELLANEOUS	3523	20.78	83.09
DEBRIS	3215	18.96	79.59

* Empty stomachs are not included in the total number of crabs.

Table. 3.15. POINTS OF MAJOR FOOD GROUPS IN VARIOUS SIZE GROUPS IN *PORTUNUS PELAGICUS.*

SIZE CLASS	NUMBER	CR	MR	FR	MS	DR	TOTAL
61-80	9	147 (27.7)	49 (9.2)	13 (2.4)	102 (19.2)	220 (41.4)	531
81-100	93	1360 (28.2)	729 (15.1)	504 (10.4)	1015 (21.0)	1222 (25.3)	4830
101-120	132	1713 (26.9)	1117(17.5)	1068 (16.8)	1379 (21.6)	1099 (17.2)	6376
121-140	59	838 (28.9)	486 (16.7)	561 (19.3)	603 (20.8)	415 (14.3)	2903
141-160	37	63 (6.5)	83 (8.6)	299 (30.8)	288 (29.7)	237 (24.4)	970
161-180	13	52 (16.3)	39 (12.2)	61 (19.1)	136 (42.5)	32 (10.0)	320

* % is given in the parenthesis

CR- Crustacean remains; MR-Molluscan remains; FR-Fish remains; MS-Miscellaneous; DR-Debris.

Table.3.16.POINTS OF MAJOR FOOD GROUPS DURING VARIOUS MONTHS IN *PORTUNUS PELAGICUS*

MONTHS →	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
NUMBER →	27	38	20	45	9	32	34	16	28	40	24	29
COMPONENTS ↓												
CR	380	521	265	668	107	500	646	236	412	447	306	469
%	32.84	27.08	26.45	28.97	24.32	27.98	31.04	31.85	30.77	28.22	31.29	34.82
MR	181	334	132	384	62	249	344	109	169	227	153	223
%	15.64	17.36	13.17	16.65	14.09	13.93	16.53	14.71	12.62	14.33	15.64	16.56
FR	136	427	143	363	48	239	203	106	176	269	225	202
%	11.75	22.19	14.27	15.74	10.91	13.37	9.75	14.3	13.14	16.98	23.01	15
MS	224	347	261	501	121	407	550	125	313	313	126	199
%	19.36	18.04	26.05	21.73	27.5	22.78	26.43	16.87	23.38	19.76	12.88	14.77
DR	236	295	201	390	102	392	338	165	269	328	168	253
%	20.4	15.33	20.06	16.91	23.18	21.94	16.24	22.28	20.09	20.71	17.18	18.78
TOTAL	1157	1924	1002	2306	440	1787	2081	741	1339	1584	978	1347

* % is given in the parenthesis.

Crustacean remains; **MR**- Molluscan remains; **FR**- Fish remains; **MS**- Miscellaneous; **DR**- Debris.

The juvenile crabs (< 80 mm CW) preferred debris (41.4%) followed by crustaceans (27.7 %) and miscellaneous items (19.2 %). In subadult group (81-100mm CW), crustaceans (28.2%) were the major food item followed by debris (25.3%) and miscellaneous (21.0%). In adults (100-140 mm) , crustaceans were the principal food item, whereas in higher size group of adults (141-180 mm) fish and miscellaneous were the major item of food.

DISCUSSION

Knowledge of the distinguishing characteristics and size relations of sexually mature individuals is of particular importance in the study of commercially important crustaceans. Crabs of the family Portunidae are distinguished by having the dactylus of their fifth pereiopods enlarged and flattened, which facilitate swimming. In the Indo-pacific region, the genus *Portunus* generally include those of the family that has nine antero-lateral spines, the last of which is enlarged. All these characters are agreeable to *Portunus pelagicus.* However, in this species sexes are easily differentiated from their colour pattern of the exoskeleton. Males are brilliantly coloured with bright blue and females with dull brown colour. This unique feature is not seen in other common portunids. Gross morphological differences in external anatomy between sexes are similar to other portunid crabs (George, 1963; Ryan 1967 a, b; Johnson, 1980; Sumpton, 1990b; Balasubramanian, 1993; Anil, 1997).

The results of length-weight relationship in *P. pelagicus* indicate that in juveniles and pre-adult crabs, weight gain is almost uniform; females are slightly heavier than males till they attain 120-125 mm carapace width. Thereafter males are heavier than females at any given length. Sukumaran and Neelakantan (1997b) found the weight increase was evident above the carapace width of 115 mm in *P. pelagicus.* The tendency of males heavier than females in portunids is in conformity with the observation of Potter et al (1983) in *P. pelagicus,* Thomas (1984) in *P. pelagicus* and *P. sanguinolentus* from Cochin, Sukumaran *et al.* (1986) in *P. Sanguinolentus* from Mangalore, Prasad *et al.* (1989) in *P. Sanguinolentus, P. Pelagicus and Scylla serrata* from Karwar and Sukumaran and Neelakantan (1997 b) in *P. pelagicus* and *P. Sanguinolentus* from Mangalore. However, from the reports of these workers it is

understood that there are marked variations in the results of carapace width-weight relationship in portunids from different places and within the various regions of the same coast. Contradictory to the result and reports of above workers, Dhawan *et al.* (1976) found that females of *P. pelagicus* are heavier than males at a given length in Goan waters. While studying the length-weight relationship of the Indian horse shoe crab *Tachypleus gigas*, Chatterji *et al.*(1994) reported males were heavier than females at smaller sizes whereas females were heavier than males at larger sizes. The present results do not tally with his findings.

The exponential values (b) of the carapace width-weight relationship males and females showed marked variation from the cube law, a marked departure from the isometric pattern of growth. In the case of carapace length-weight relationship, males followed isometric growth pattern while in females significant departure from isometric growth is evident. The results of analysis of covariance indicated a significant difference between sexes in respect of carapace width/length-weight. The present findings are in conformity with the findings of Sukumaran and Neelakantan (1997b) in *P. pelagicus*. The same author observed isometric growth in males and females of *P. sanguinolentus*.

Sex ratio plays an important role in population biology, which is especially essential for any commercial species, as it serves as the basis of estimating gains precisely in *P. pelagicus*. Sex distribution in relation to size in *P. pelagicus* did not show any clear pattern and ratio varied in different size groups in both gears studied in all the stations. The same condition has been reported by Sukumaran and Neelakantan (1997c).

The dominance of females in trawl catches confirm their migration towards deeper waters for breeding. While in *nanduvalai*, a near shore gear males dominated the catch in majority of the months. The chi-square values for the pooled data for all the centres were significant enough to reject the null hypothesis *i.e.*1:1 ratio. The results of the present study are in conformity with the observations of Sukumaran and Neelakantan (1997c) in *P. sanguinolentus* and *P. pelagicus*. However, Lalitha Devi (1985), Sukumaran *et al.* (1986) and Kurup *et al.* (1990) reported 1:1 male-female ratio representing a non-significant chi-square value in the case of *Scylla serrata*, *P.*

sanguinolentus and *P. pelagicus* respectively. Differential mortality, habitat segregation by sex and single sex migration have been used to explain the divergence of many marine crustaceans from 1:1 sex ratio (Wenner, 1972).

The general structure of the male and female reproductive system in *P.pelagicus* conforms to the general pattern in other brachyuran crabs, where, both the systems are roughly in the form of 'H' (Cronin, 1947; Estampador, 1949; George, 1963; Ryan 1967b,c; Haefner, 1977; Johnson, 1980; Melville-Smith 1987; Wenner *et al.,* 1967, Balasubramanian, 1993; Anil, 1997). In adult males, the internal organ consists of a pair of testes, which are medially inter-connected and paired vas deferens which are again differentiated to three regions, the anterior, middle and posterior vas deferens. The external sexual organs include paired penes and first and second pleopods which together help in the sperm transfer. Cronin (1947) and George (1963) observed a distinct vas efferens, as a small tube, which is embedded in the anterior vas deferens which, is not easily distinguishable. There was no distinct vas efferens between testes and anterior vas deferens. According to Ryan (1967a) this vas efferens is just a specialized end of the anterior vas deferens. Ovaries are paired, occupy the same position as the testes in males, however the fully mature ovaries adhere to the inner surface of the carapace and difficult to detach without any damage. Medially inter connected ovaries are 'H' shaped and at the mid-lateral border they are connected with spermatheca which in turn communicate with the exterior by vagina. Their structure closely resembles and agrees with the reports of earlier workers (Pearson 1909; Cronin, 1942; Estampador, 1949; George, 1963; Ryan, 1967 b, Melville-Smith, 1987, Balasubramanian 1993; Anil, 1997). It is observed that there was no consistency in the relative length of the ovarian lobes, as the posterior prolongation on one side remained to be either shorter, or longer than the other side. George (1963) noticed in *P. sanguinolentus,* posterior prolongation on the right side of the ovary to be shorter and narrowed than the left side. In the present study, it is observed that there was no consistency in the relative lengths of the lobes of the ovary on the two sides as the posterior relative lengths of the lobes of the ovary on the two sides as the posterior extension remained equal or on one side shorter or longer than on the other side.

Only a few workers have described well-defined maturity stages in portunid crabs. Haefner (1976) described 6 stages in males of *Cancer irroratus.* Aruldhas *et al.* (1980) reported five maturity stages in *P. pelagicus,* while Sukumaran et. al (1986) come across four maturity stages in *P. sanguinolentus* excluding the spent stage. Jacob *et al.* (1990) described four maturity stage in females of *P. sanguinolentus and P. pelagicus.* The GSI values in immature and early maturing females are almost similar to the observations of Jacob *et al.* (1990) while the mature ovaries showed a higher range.

It has been reported by Stephenson (1934) that the species occurring in tropical waters may exhibit several types of breeding cycle *i.e.* continuous breeding, discontinuous breeding during greater or shorter period in an year, two spawning periods and a single breeding season. According Pillai and Nair (1971, 1973b) who studied the reproductive cycles of *P. pelagicus* from south west coast of India observed breeding is not continuous all the year round but extends over several months of the year with distinct peak periods of gonadal activity.

During the present study it was found that berried females are available throughout the year which conforms well to the observations of Prasad and Tampi (1953) and Rahman (1967) from the East Coast. In *P. pelagicus,* the apparent differences in the breeding season on the east and west coasts may be due to the different hydrological conditions prevailing in the inshore waters of the west coast of India. It was observed, in the landed crabs, some are in the earlier stages of maturation, some are matured and some are with berry. Panikkar and Aiyar (1939) and Giese (1959) have reported this nature of asynchronous breeding.

Balasubramanian (1993), while studying the deep water crab *Charybdis smithii* found no maturation process is taking place in these crabs during the pelagic phase. Studying the distribution of the offshore crab *P. affinis*, Jerde (1967) noted the absence of ovigerous crabs in the pelagic habitat.

Sumpton *et al.* (1989) found that the smallest sexually mature male and female *P. pelagicus* measured 83 mm and 73 mm CW respectively in Australian waters. Later in 1994, the same authors reported that most crabs of the sizes above 90 mm were to be sexually mature in the same area. Reeby *et al* (1990a) reported that the

onset of sexual maturity in male was at 81-85 mm CW in *P. sanguinolentus* and 86-90 mm CW in *P. pelagicus*. Jacob *et al.* (1990) found that females of these two species attain sexual maturity at 81-85 mm CW and above. In the present study the size of the smallest mature male and female was 82 mm and 88 mm CW respectively, while Sukumaran (1995) reported a minimum size of 88 mm in males and 82 mm for females in *P. pelagicus* and respective sizes of 83 mm and 78 mm in *P. sanguinolentus*.

The smallest ovigerous females of *P. pelagicus* were observed by Thompson (1951) from Australia, Prasad and Tampi (1953) from Mandapam, Pillai and Nair (1971) from south west coast of India, Radhakrishnan (1979) from Porto Novo and Thomas (1984) from Cochin, which measured 106, 92, 93, 113 and 92 mm respectively. In the present study the size of the smallest berried crab was 105 mm/ 90 g.

Pillai and Nair (1973b) reported the fecundity of *P. pelagicus* varied between 180400-463730 in the size range of 95-164 mm cw from Cochin backwaters while Joel and Raj (1980) reported a range of 10,800-4,00,000 from Pulicat Lake. According to Reeby *et.al* (1990b) the fecundity of the same species from Karwar waters varied between 80,281 to 862725 and Sukumaran and Neelakantan (1997a) found it was between 56,000 and 10,70,000 from Mangalore waters. However, the present study shows high fecundity, between 60,000-1976398 in the size range of 100-190 mm CW, which is a record for the Indian region. Fecundity estimation by Campbell (1984) in Australian waters recorded a higher fecund number than the present study (approximately 2.4 million). In a closely related American blue crab *Callinectes sapidus* Prager *et al.* (1990) observed a mean fecundity of 3.2 million.

Environmental conditions and ample food supply are known to influence the fecundity of marine organisms (Bagenal, 1957). The wide variations observed in the fecundity at different regions may be attributed to the prevalence of different environmental conditions and food availability. Differences in fecundity occur during different reproductive periods, at different times within any reproductive period and different locations throughout a geographic area (Hines, 1982; Prager *et al.*, 1990; Shields *et al.* 1991 and Kennelly and Watkins, 1994). The number of eggs

carried by *P. pelagicus* increased with respect to its size (carapace width) and significantly related to carapace width rather than the weight of the crab. However, Carsen *et al.*(1996) reported a significant relationship between fecundity and carapace length in *Platyxanthus patagonicus.* Giese and Pearse (1974) opined that several factors such as salinity, temperature, photoperiod, abundance of food *etc.* in the environment and intrinsic state of animal attributed to both interspecific and intraspecific variability of fecundity. There has been considerable variation in total egg production among the crabs of same size group. This is in conformity with the findings of Prasad and Neelakantan (1989) in *Scylla serrata* and Sukumaran and Neelakantan (1997a) in *P. pelagicus.* The positive relationship found between the number of eggs and size of the females is consistent with observations made for other species of crabs, *Geryon* quinquedens (Hines, 1988), *Chinoecetes opilio* (Sainte-Marie, 1993) and *Ranina ranina* (Kennelly and Watkins, 1994).

Crustaceans serve as hosts for both ectosymbionts and endosymbionts, some of these associations are standard text book examples such as the dromiid crabs, which invest themselves with sponges and the brachyuran crabs, which are parasitized by the *Sacculina* (Ross, 1983). Hartnoll (1962) described the parasitic castration in the crab *Macropodia longirostris* by a sacculinid. In his report he mentioned about double infection in three of the crabs. Meanwhile Takahashi and Liitzen (1998) reported that multiple externae was common in the intertidal crab *Hemigrapsus sanguinens,* which is parasitized by *Sacculina polygenea.* However, in the present study no crab with multiple externae was encountered. He also opined that two different populations may differ in parasite attack also. In the present study also it was obvious that crabs caught from Devipattinam area are more inclined to parasitization than Mandapam and Thoppukkadu. Devipattinam, where the sea grass exhibits luxuriant growth might serve as a congenial environment for the parasite too. Reports of parasitization on crabs by *Sacculina* (Boschma,1968) agree with the present work.

Due to the procedure of recording only crabs with externae being parasitized and to the considerable difficulties involved in detecting rhizocephalans during the internal phase, prevalence of parasitisation are underestimated. The same problem

was also raised by Lazaro-chavez *et al.* (1996) in their studies on the crab *Callinectes sapidus.* Another reason may be that Sacculinid rhizocephalans usually do not have visible externae on host crabs before the parasites attain a size of normal maturity as suggested by Takahashi and Liitzen (1998). The present findings are also in conformity with their findings.

The young crabs are free of barnacles, as they shed their exoskeleton more frequently than the adults. In adult crabs the intermoult period is longer and the organism gets enough time for its settlement. The egg carrying crabs have a characteristic appearance; their abdomen being dirty looking and discoloured and their shells are usually heavily encrusted with epifauna such as barnacles, Saddle oysters (*Anomia)* and tube worms (Edwards, 1979). In the catches the number of barnacle encrusted females were more, probably due to prolonged intermoult period in matured and berried females. There are reports of encrustation with barnacles and other organisms in Stone crab *Menippe mercenaria* and blue crab *Callinectes sapidus* (Eldred, 1961 and Lazaro-chavez *et al.*,1996).

The diet of *Portunus pelagicus* was similar in several aspects to the diet of other portunid crabs. They are opportunistic omnivores with preference for animal prey, but rarely feed on more mobile prey such as fish and prawns (Patel *et al.* 1979 and Williams, 1982). Warner (1977) is also of the opinion that crab carry over the primitive habit of being opportunistic omnivores with a preference for animal food in conjunction with predatory propensity. In the present study it is observed that crustaceans are the most favoured item followed by molluscs and fishes. It is in conformity with the findings of Patel *et al.* (1979), while Sukumaran and Neelakantan (1997b) reported *P. pelagicus* from Mangalore coast preferred crustaceans followed by fishes and molluscs. The wide foraging strategy of *P. pelagicus* is also typical of other portunid crabs. All the studied species are reported to consume mixed diets of molluscs, crustaceans, fishes, polychaetes similar to *P. pelagicus (Carcinus maenas:* Ropes, 1968; *Scylla serrata*: Hill, 1976; *Callinectes sapidus:* Laughlin, 1982; *Scylla tranquebarica* and *S. serrata:* Joel and Raj, 1986; *S. serrata:* Prasad and Neelakantan, 1988b; *Thalamita crenata:* Cannicci *et al.* 1996). Presence of detritus (79.59%) in the stomachs examined suggest that these crabs are

detritivorous consuming fresh and decaying flesh of all kinds in the present study. It is found that stomachs of juveniles and sub-adults are pre-dominated with debris. Menon (1952) and Patel *et al.* (1979) have reported presence of good amounts of organic matter mixed with sand, mud, gravel and bottom particles showing its bottom feeding habits and bottom dwelling habitats. A good amount of detritus in their guts has shows that *P. pelagicus* is also an opportunistic deposit feeder as reported by Prasad and Neelakantan (1988b) in *S. serrata.* The detrital energy assimilated by the crab population is converted into body tissues (Macintosh, 1984).

Many portunids also consume small quantities of macrophytes. The adult crabs of *Liocarcinus puber,* are found to consume plant material (brown algae) by preference (Choy, 1986). Grapsid, Xanthid, majid, potamid and portunid (particularly juveniles) crabs have also been reported consuming plant material (Hartnoll, 1963; Ropes, 1968; Hill, 1976; Warner, 1977; Paul 1981; Jewett and Feder, 1982; Williams, 1982 and Rosas *et al.* 1994). In the present study, stomachs of juveniles and sub-adult crabs were comprised of semi-digested plant materials like seaweeds and sea grasses.

There was no significant difference in the quantity of the food consumed by males and females as reported by Williams (1981), Jewett and Feder (1982), Sumpton and Smith (1990) and Wieczorek and Hooper (1995). Feeding generally takes place every day throughout the year, except during few days of moulting and mating when feeding ceases or it is at its minimum. Majority crabs with empty stomachs encountered during the study were either in berried condition or in advanced stage of `pre-moult'. Choy (1986) also reported empty stomachs in gravid females and parasitized crabs. Jewett and Feder (1982) reported that feeding increases during spring in King crab *Paralithodes camtschatica.* However, in *P. pelagicus* no such variation was observed, as India being a tropical country and does not have such sharp seasonal differentiation. Balasubramanian (1993) reported that the feeding intensity is comparatively low among the adult crabs found at the bottom waters in *Charybdis smithii.* Jewett and Feder (1983) concluded that small crabs feed more intensively than larger crabs, since the moulting frequency among the smaller crabs is greater and energy demand is more.

It is not possible to confirm from stomach contents whether prey had been alive or not when preyed. Caine (1974) had explained a prey catching mechanism in portunid crab, *Ovalipes guadulpensis*, but Hill (1976) could not observe such technique in *S. serrata.* Prasad *et al.* (1985) have observed the crabs catching live prawns in prawn culture field during harvesting seasons. However, in the present study, when *P. pelagicus* was reared along with juvenile shrimps of *Penaeus semisulcatus,* there could not be observed any active predatory attempts. Hence, the incidence of animal remains in the gut contents might indicate that the crabs might have opted for dead and decaying material by scavenging. While, the presence of crab exoskeleton in stomach content shows that they are cannibalistic. Cannibalism was observed on several occasions in the rearing tanks especially during moulting, when the bodies of the newly moulted crabs are soft and vulnerable to attack by the hard crabs. In the present study during several occasions it was observed that crabs were consuming the exuviae of other crabs. Hence there are ample chances that the crab remounts recorded from the stomachs may be from cannibalistic consumption. Thus the present study and the related studies suggest that despite the diversity in crab diets and feeding habits, portunid crabs are opportunistic omnivores with a preference for animal food.

CHAPTER IV

CHAPTER IV

LARVAL REARING, GROWTH AND MATURATION UNDER LABORATORY CONDITIONS

INTRODUCTION

Crustaceans are characterised by the presence of an exoskeleton, which must be shed in order to attain growth, and the process is known as moulting or ecdysis. The animal will undergo discontinuous growth, through successive moultings; the intervals between two moultings being divided into postmoult, intermoult and premoult. At ecdysis, the animal emerges from its old depleted encasement with a newly synthesized pliable, paper thin exoskeleton, that is stretched to its new volume by an uptake of water from the environment and in consequence an expanded haemocoel. Each moult cycle is clearly set off by shedding of the old exoskeleton but both before and after ecdysis there occur major metabolic events specifically associated with growth. These include the degradation of the old exoskeleton and synthesis of several layers of a new exoskeleton, formation of gastroliths in some species, atrophy of somatic muscle in the chelae that is replaced following ecdysis and regeneration of missing pereiopods (Skinner, 1985).

It is believed that, y- organs are the source of moulting hormone, which initiate and support some, possibly all preparations for moulting including the pro-ecdysial growth phase of regeneration. Echalier (1955) elucidated the role of these glands in moulting of the crab *Carcinus maenas*, extirpation of these glands blocked moulting, whereas implantation restored it. Y-organs secrete three different ecdysteroids, identified as ecdysone (E), 25-deoxyecdysone (25 DE) and 3-dehydroecdysone (3 DE) and injection of these hormones in intermoult animals induces the initiation of ecdysis processes (Lachaise *et al.*, 1993).

Hiatt (1948) studied the moulting and associated increments in body size of the lined shore crab *Pachygrapsus crassipes* Randall. Menon (1952) conducted studies on the growth of *Portunus sanguinolentus* by laboratory rearing with minced clam meat. Prasad and Tampi (1954) gave detailed account of relative growth of various body parts of *P. pelagicus* in relation with the carapace. Butler (1961) carried out growth and age determination of the Pacific Edible crab *Cancer magister*. Kurata

(1962) identified the factors determining the length of the intermoult period. Effects of temperature on growth and metabolic rate of juvenile blue crabs were dealt by Leffler (1972). Annual growth of the crab *Cancer pagurus* (Bennett, 1974) in Southwest England was described. Mauchline (1976) gave the Hiatt growth diagram for crustacea and Carroll (1982) gave growth curve for *Cancer antennarius*. Seiple and Salmon (1987) gave different growth characteristics of *Sesarma cinereum* and *S. reticulam*. Maturity studies in *Scylla serrata* was described by Prasad and Neelakantan (1989, 1990). A growth model for deep sea red crab, *Geryon maritae* off Southwest Africa was given by Melville-Smith (1989). Autotomy and its effect on growth was studied in the blue crab, *Callinectes sapidus* (Smith, 1990). Sumpton *et al.*(1989) studied the biology of portunid crab *P. sanguinolentus* from Queensland waters. An account of sexual maturity in *Portunus pelagicus* and *P. sanguinolentus* has given by Jacob *et al.* (1990). Reeby *et al.* (1990a) investigated age and growth of *P. pelagicus* and *P. sanguinolentus*. Kondzela and Shirley (1993) and Wainwright and Armstrong (1993) gave growth studies in Dungeness crabs. Sukumaran and Neelakantan (1996a,b; 1997b) described sexual maturity, age and growth parameters in *P. sanguinolentus* and *P. pelagicus*.

In India *P. pelagicus* is caught commercially and a study of its larval development and growth will be useful for its future farming. Earlier Indian works on these aspects (Prasad and Tampi, 1953; Chhapgar, 1956; Ameer Hamsa, 1982 and Raman *et al.*,1987, Josileen-Jose et al., 1996,1998) are incomplete and no detail larval description is available except for the first zoea. This chapter deals with the complete life history of *P. pelagicus* , hatched and reared in the laboratory.

MATERIALS AND METHODS

Larval rearing experiments

Collection of broodstock : *Portunus pelagicus* is a continuous breeder, so the berried crabs are available throughout the year. Healthy ovigerous females with characteristic yellow/orange coloured eggs were collected from sea and brought to the laboratory in 50 litre white jerry can with sea water. These crabs were kept in 1.5 t capacity fiberglass tanks at a salinity of 35 ± 1 ppt, pH 8.2 ± 0.1 and temperature 28 ± 2° C

with continuous aeration. Gravity sand filtered seawater was used for the entire rearing operation and 50% of water exchange was given daily. Fresh clam meat and fish meat were given as feed.

Hatching of zoeae : The changes in the egg colour is observed daily and when the egg mass became deep grey that particular female crab was transferred into a separate tank with known volume of seawater (around 500 liters) during evening hours. The total weight and carapace width were measured. No feeding is required at this stage as the mother crab does not eat but tank must be cleaned and water exchange should be given till of hatching.

After full hatching mother crab was removed from the tank and weight of the crab was taken. In hatching tank aeration was stopped for few minutes allowing the empty eggshells and un-hatched eggs to settle at the bottom. These were removed carefully without disturbing the live zoeae in the water column and surface.

Mass culture of marine *Chlorella* – rotifer (*Brachionus plicatilis*, Indian strain)

"Groundnut oil cake method" (GOC) : Rotifers *Brachionus plicatilis* are mass cultured under-roof in one ton fibreglass tank by "semi-continous batch culture" method. Clean, filtered seawater is pumped into the tank and fertilized at the rate of, 250g GOC, 10g urea and 5g super phosphate per ton. GOC is water-soaked the previous day of *Chlorella* inoculation and filtered through 150μ filter bag. The thoroughly mixed chemicals are added to the seawater and mixed thoroughly. Fifty litres of *Chlorella* at a cell concentration of 20-30 million cells/ml is added as inoculum and good and continuous aeration was provided. The tank is placed below the translucent roofing assuring good sunlight. On day 4, when good bloom of *Chlorella* is attained rotifers are inoculated in the tank at a rate of 25-50 nos./ml. On day 8, density of rotifers is found to be 200-250 nos./ml. Aeration is stopped for 10-15 minutes before partial harvesting, which allows the debris and organic particles to settle at the bottom. The required quantity is collected using 60μ filter bag. The collected rotifers are thoroughly washed in filtered running seawater and finally passed through a 250μ filter bag to eliminate the bigger 'unwanted' materials. Cleaned rotifers are directly supplied to the crab larval rearing tanks. In this semi-

continuous method, after harvesting a part of rotifer along with the culture water, an equal quantity of *Chlorella* water is replaced and the culture is maintained for 3-4 weeks with daily harvests.

"Chemical method": *Chlorella* is also mass-produced by using inorganic chemicals; the requirements for a ton of seawater are given below.

Chemical	Quantity (g)
Ammonium Sulphate	100
Urea	5
Super Phosphate	20
Mineral Mix	10

Chemicals are thoroughly mixed with seawater and *Chlorella* as well as rotifers inoculum are added as in the GOC method.

The advantage is that there will not be any impurities as in GOC method, but the algal concentration will be less (≈10 million per ml.) and it is possible to keep good algal bloom only for one week.

The rotifers are checked before it is fed to the larvae and before inoculation, for any contamination, particularly with ciliates.

***Moina macrura* culture**

Fresh water *Chlorella* is mass-produced in the hatchery like the marine *Chlorella* and the same procedure for rotifer mass production is followed for *Moina* also.

Mass culture of *Chaetoceros* spp.

For starting *Chaetoceros* culture, good quality fresh sea water (30-35 ppt.) is filtered through a 50 μ bolting cloth (500-1000 litres) and filtrate is added to the fertilized sea water. The chemicals used for fertilizing one ton of sea water is given in the following table.

Chemical	Quantity (g)
Potassium nitrate	12
Sodium orthophosphate	6
Sodium silicate	6
EDTA di-sodium salt	6

Good aeration is provided to the culture tank. The intensity of the sunlight varied between 20000 and 100000 lux during day time and the temperature of the culture water between 28-34° C. Under these conditions the diatom cells present in the sea water multiply rapidly and give a golden-brown bloom of diatoms within a period of 24-48 hrs. In this culture, *Chaetoceros* spp. become the dominant (around 90%) and the rest by *Thalassiosira, Skeletonema* and *Nitzschia*. The concentration of diatom cells in a culture ready for use is 3-4 lakhs cells/ ml of the culture. This is used for feeding as well as for inoculating the batch cultures on successive days. Cultures are started every day using the previous day's culture for inoculating (@ 30-35 litres /ton of seawater) the filtered seawater fertilized with the chemicals as given above.

Preparation of egg-prawn custard

Cleaned and deveined small prawns like *Metapenaeus* spp. and yolk and albumen of hen's egg are the two ingredients used for this preparation. These are mixed well in a mixer grinder at a ratio of 1:5. The mixture is cooked for 15 minutes in a pressure cooker without weight. It is cooled to room temperature and then kept in a refrigerator. The solid block of this custard, after thawing is made into suitable particle size by passing through appropriate sieves. It is better to use the custard fresh and do not store it for more than 3 days.

Larval rearing

Four pure microalgal feeds *viz. Chaetoceros, Chlorella, Tetraselmis, Isochrysis* and a combination of *Chaetoceros* + *Chlorella* and were given for the first zoea to find out the best suitable algal feed for that stage. For the subsequent three zoeal stages three different live animal feeds *viz.* live rotifers (*Brachionus plicatilis*), freshly hatched *Artemia* nauplii and combination of both were given to select the suitable feed for these stages. Among the different microalgae *Chaetoceros*

gave best result, hence in this trial only *Chaetoceros* fed zoeae were used. In all the experiments, Megalopae were fed with *Moina* and egg-prawn custard in addition to the respective zooplankton. Zoea- IV onwards phytoplankton feed was not supplied to the larvae. In all the trials no feed was given to the control.

Feed trials were conducted in 10 litre glass beakers. The same type of beakers were used in the experiments to find the optimal larval stocking ~~the larval~~ density. The larvae were stocked in different stocking densities (10 nos./l, 25 nos./l and 50 nos./l) to find out the suitable stocking levels in mass culture.

Single species culture of phytoplankton was obtained from the microalgal culture laboratory. Zooplankton like rotifer and *Moina* were raised in the laboratory to meet the feeding requirements. In the case of *Artemia* commercial cysts (OSI brand) were purchased and hatched in the laboratory to the need. Filtered seawater was used except for *Moina* culture, which was raised in freshwater. Utmost care was taken while supplying phytoplankton feed; only fresh cultures in their exponential growth phase was given as feed.

The larval rearing beakers were daily observed for successive developmental stages, moulting of larvae and exuviae. 50 % of the water was exchanged in the morning hours and fresh feed was given.

When the larvae reached last stage of zoea different substrata like old nylon ropes, polypropylene fishing nets, pieces of corrugated asbestos sheets, PVC pipes, edible oyster shells and seagrass were placed in the larval rearing system to study which one would be the best for the attachment of megalopae larvae. When the megalopae metamorphosed into first crab stage, they were transferred into a tub with sand bottom and similar water quality parameters. At each developmental stage larval count was taken to calculate the survival of larvae in each stage.

Camera lucida drawings of the different zoeal and megalopal stages were made from the larvae preserved at a known stage of development. The detailed drawings of the appendages of each stage are also drawn to the scale from appendages dissected out with fine needles.

Growth studies

Growth of crabs from first instar to sixteenth instar was studied by rearing

crabs in the laboratory. For this purpose baby blue swimmer crabs were produced in the laboratory. Forty-five healthy juveniles of 2.0-2.5 mm carapace width were used for the experiments (total 3 trials with 15 numbers in each).

First these instars were stocked in two litre capacity plastic tubs till they attained the size of 10 mm and then they were transferred to 30 litre capacity plastic tubs till a minimum size of 35 mm. Always plastic tubs were provided with sand bottom and small shelters. These experiments were conducted in 35 ±1 ppt filtered seawater. Ninety percent water exchange was done daily morning between 0830 and 0930 hours. Animals were fed with egg custard till the size of 10 mm CW and later sizes with fresh clam meat and small prawns. Everyday before feeding excess feed and faecal matter were siphoned out and water was replaced. Continuous aeration was provided to each tub. The tubs were arranged in such a way that all of them receive uniform light exposure. Animals were daily observed for moulting and after each moult, and after sufficient hardening morphometric and weight measurements were taken. The exuviae were collected and preserved.

The young crabs above the size of 35 mm were transferred to a one ton capacity fibreglass tank provided with sand bottom and pieces of corrugated asbestos sheets and coral stones as shelters. Each animal was given a number, the label being attached to its carapace and readily visible through the water column (using "Letro" label maker). This was useful for identifying the moulted crab (Plate 9.a). After each moult new label was attached to crab's carapace and measurements were taken after only sufficient hardening of the exoskeleton. Daily water exchange (75%), feeding, etc. were carried out as mentioned in the previous paragraph.

Maturation system

Maturation system for crabs was developed in the hatchery following the methods suggested by Maheswarudu *et al.* (1996). A collapsible polyvinyl pool of 8' diameter with 8 t capacity was used for this purpose (Plate 9.b). An insitu sand bed filter of 5-10 cm height was set on a perforated false bottom erected at about 15 cm height over the entire bottom of the maturation pool. Four PVC tubes of 1 m height and each with 50 mm dia. were fixed vertically in the peripheral region of the sand bed at equal distances. Water column in the pool above the sand bed was maintained

Plate 9

a

b

a. Experimental crabs with 'identity stickers' on the carapace

b. A collapsible polyvinyl pool (8' dia.) used for crab maturation studies

at 0.75 m depth. The crabs above the size of 60mm carapace width were transferred into the pool. Water recirculation was maintained at the rate of 300% by lifting the filtered seawater from below the sand bed through PVC pipes with a lid to reduce light intensity. Air water lifting system was arranged in the tank through air dispersing stones. Daily 25-30% water exchange was given and once in a week 100% exchange was given. Water pH was maintained at 8.0-8.2 by addition of sodium carbonate whenever necessary. Individual numbers were given to the crabs as mentioned earlier. Daily the animals were fed *ad libitum* with clam meat/ shrimp/ squid meat in the morning and evening hours. Faecal matter and unused feed were siphoned out in the morning hours before water exchange was given. Animals were observed regularly especially the female crabs for spawning and its frequency in each moult cycle.

Water quality was maintained in the ideal range as those factors play important role in successful growth and maturation in captivity. Salinity, temperature, pH, dissolved oxygen, total ammonia and nitrate were the parameters monitored and kept optimal regularly. Tank water temperature was maintained between 28-30^0 C and dissolved oxygen between 5-7 mg/l. Temperature was monitored using a centigrade thermometer graduated 0-50°C. A digital pH meter was used for the determination of pH. Salinity was determined with the help of salinometer (ACUTE, Refractometer, Japan). Nitrate, ammonia and phosphate were estimated using nutrient kit (Merck, Germany).

Few Behaviours such as cannibalism, mating, burrowing/sheltering habits were closely observed in crabs rearing for growth and maturation studies.

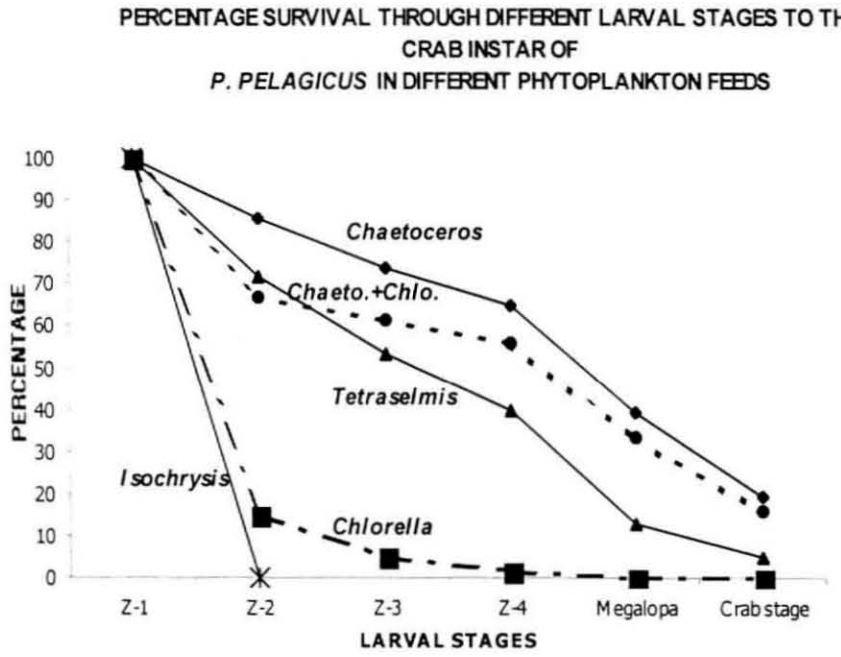
L∞ and K

Data of laboratory rearing experiments on the growth of male and female crabs were entered as a growth increment data file in the FiSAT computer programme. Further analysis of growth increment for fitting a growth curve was carried out using Gulland and Holt, Munro's and Fabens methods. The estimate of L∞ and K thus obtained were analysed using the inverse Von Bertalanffy equation to arrive at corresponding length at age. The optimum parameters (L∞ and K) were fixed based on the data obtained during laboratory growth studies.

RESULTS

Larval growth and development

Among the different phytoplankton feeds used *Chaetoceros* was found best for the first zoeal stage, followed by *Tetraselmis*, *Chaetoceros* + *Chlorella* and *Chlorella* alone. All of the crab zoeae fed with *Isochrysis* died in the 1st zoeal stage itself without moulting to the 2nd zoea. The details are given in the following figure.



For the rest of the zoeal stages a combination of *Chaetoceros* + Rotifer + *Artemia* and *Chaetoceros* + Rotifer gave best survival *i.e.* 21.0% and 20.5% respectively till the 1st crab instar. A combination of *Chaetoceros* + *Artemia* gave a survival of 6.9% only. Details of percentage of survival in successive stages are given in the following table.

Stage / feed	*Chaetoceros* + Rotifer	*Chaetoceros* +Rotifer + *Artemia*	*Chaetoceros* + *Artemia*
Zoea-II	100.0	100.0	100.0
Zoea -111	95.5	97.5	25.5
Zoea – 1V	86.0	88.0	23.0
Megalopa	42.5	45.8	13.8
1st crab instar	20.5	21.0	6.9

It was found that in mass rearing, zoeae can be stocked upto a density of 50 nos./litre. Mortality was recorded throughout the rearing period and it was more in the 1st to 2nd zoeal moult, 4th to megalopa stage and megalopa to crab stage. Among the various materials tried for the megalopal attachment, sea grass *Cymodocea serrulata* was the best followed by polypropylene nets and corrugated asbestos sheets.

The mass seed production and various aspects of management are discussed in chapter 5.

Larval stages

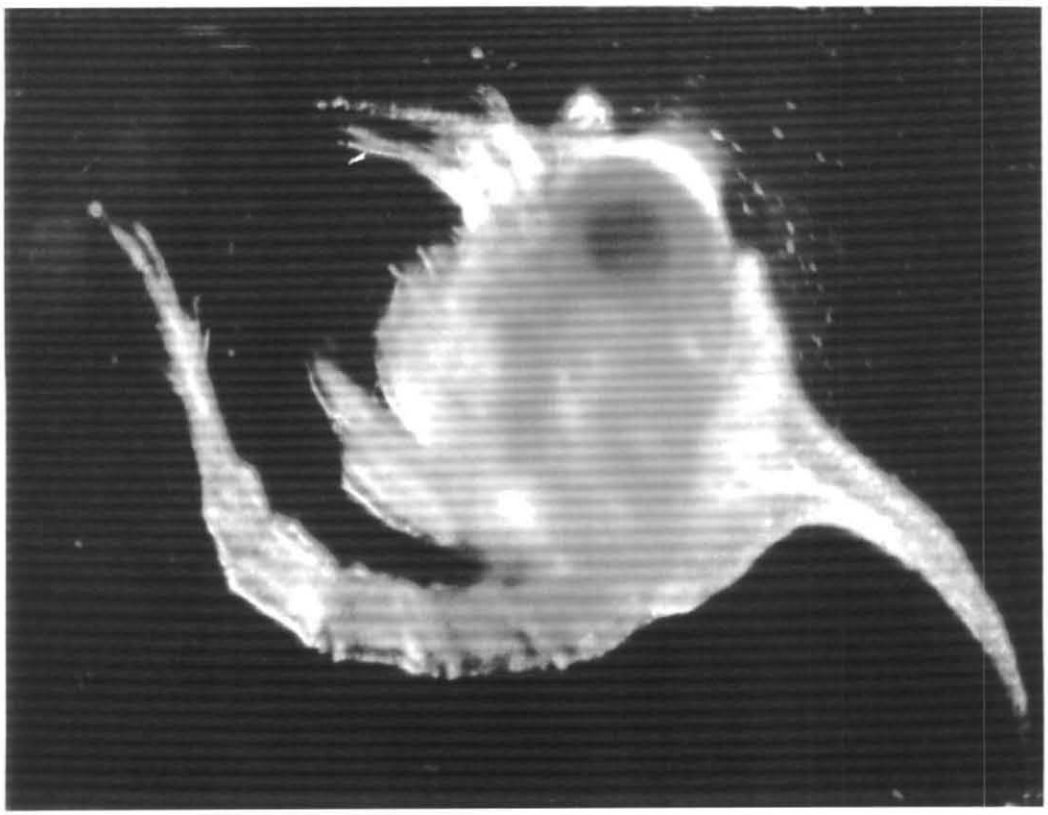
The larval development of *Portunus pelagicus* includes four zoeal stages and a megalopa stage. The megalopa stage metamorphoses into the crab stage. Zoeae are of typical brachygnath type. There are four well-defined zoeal stages that can be distinguished during the metamorphosis of first zoea to megalopa. Zoeae are with a long rostral and dorsal spines and a short lateral spine on the carapace. Carapace length (CL) was measured from the base of the rostral spine to the middle of the posterior border of the carapace and abdomen-telson length (Abd-TL) from the proximal border of first abdominal segment to the tip of the longest caudal spine (Fig. 4.1). A detailed description of each larval stage is given below.

First zoea (Fig.4.2A & Plate 10.a)

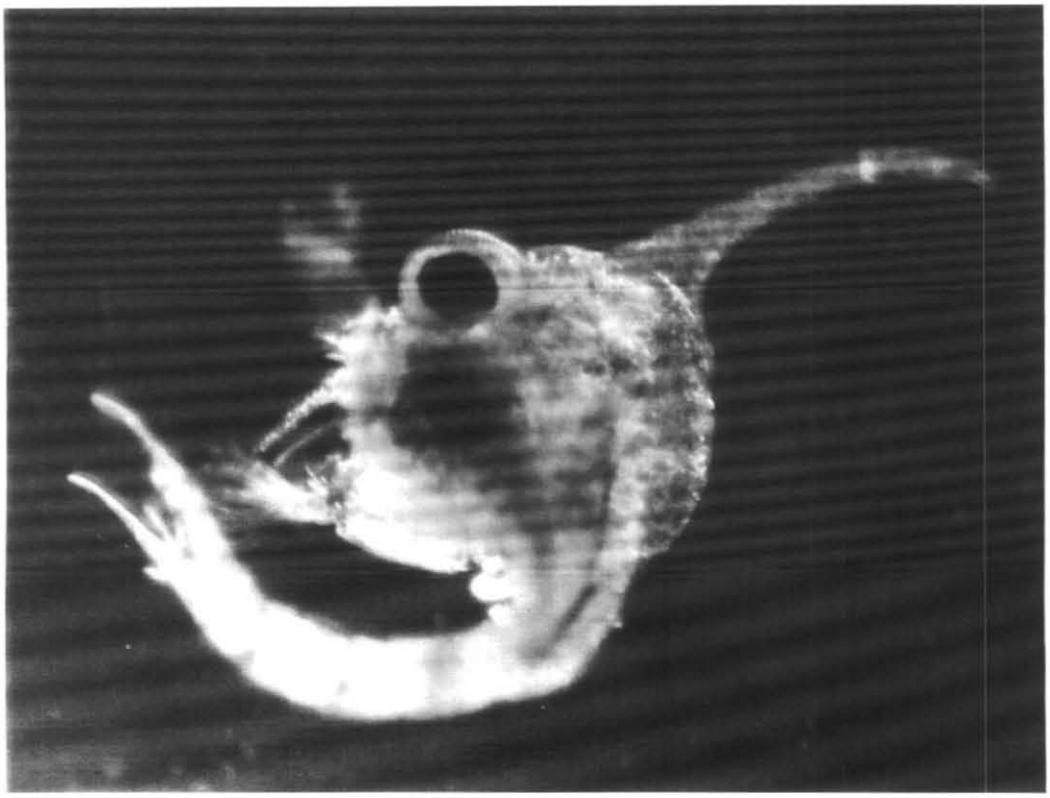
Carapace length varies from 0.44 to 0.54 mm and abdomen – telson length from 1.07 to 1.23 mm. Eyes are sessible. The first abdominal segment bears a short seta on its dorsal surface.

Antennule (Fig.4.2B) : Short and possessing a conical shape. At the tip it bears two long aesthetes of equal length and two short setae which are unequal.

Plate 10



a



b

Larval stages

a. Zoea 1 (65x)

b. zoea 2 (50x)

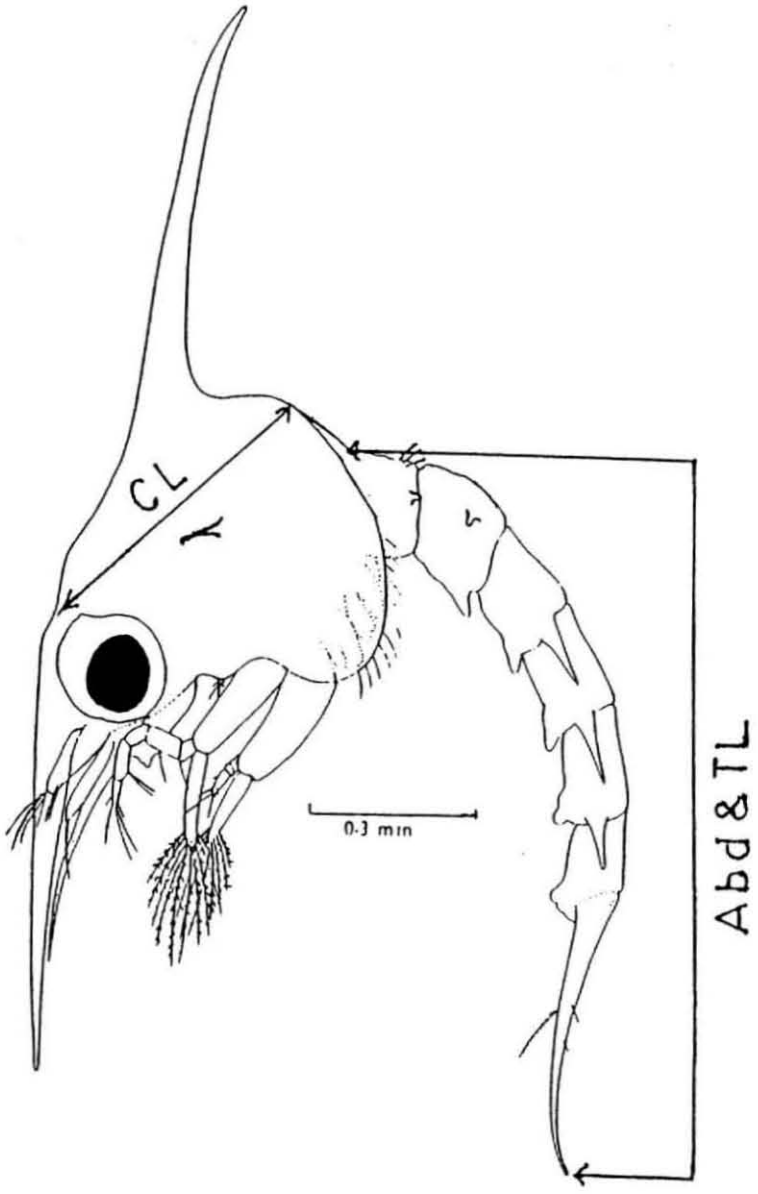


Fig. 4.1. ***Portunus pelagicus*** - Zoea (III) showing larval measurements. CL, Carapace Length ; Abd & TL, Abdomen -Telson length.

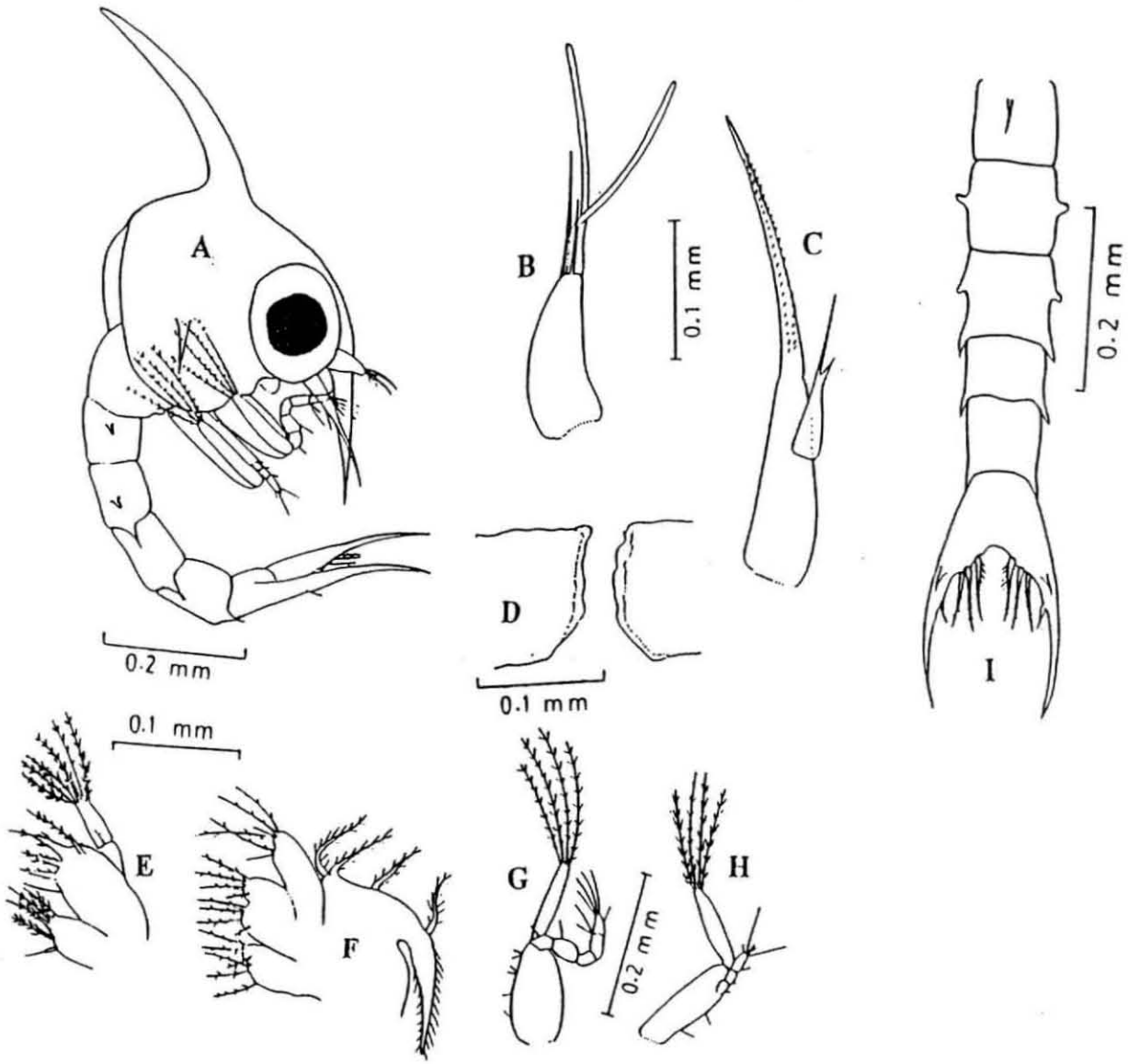


Fig. 4.2. *Portunus pelagicus* - First Zoea and its appendages.
A, zoea – I ; B, antennule; C, antenna; D, mandible; E, maxillule; F, maxilla; G, first maxilliped; H, second maxilliped; I, abdomen with telson.

Antenna (Fig.4.2C): with a long spiniform process bearing two long rows of short spines. Exopod is short with a single segment bearing two unequal setae at its distal region.

Mandible (Fig.4.2D): is small structure with broad cutting edges.

Maxillule (Fig.4.2E): Protopod with unsegmented coxal and basal endites. Basal endite with five setae which are sparsely plumose. Coxal endite with six to seven setae.

Maxilla (Fig.4.2F): Maxilla with bilobed coxal and basal endites; unsegmented endopod and a broad scaphognathite. Each lobe of the coxal endite with three plumose setae. Each lobe of the basal endite bears three plumose setae of varying length. Endopod carries four terminal and two sub-terminal setae. Some of the setae are long and plumose.

First maxilliped (Fig.4.2G): Protopod broad bearing six to seven short setae along its inner margin. Endopod five segmented bearing 1-1-0-2-5 setae counting from proximal to distal segments. Exopod unsegmented carrying 4 long plumose natatory setae at the terminal portion.

Second maxilliped (Fig.4.2H): Broad protopod bearing two to three short setae along its inner margin. Endopod four segmented bearing 1-1-1-5 setae starting from the proximal segment. Out of the five setae on the distal segment two are more than three times longer than the rest. Exopod unsegmented bearing four long plumose natatory setae at its distal end.

Abdomen (Fig.4.2I): Five segmented and a telson. Second and third segment bear on either side a short lateral knob. The knobs on 2nd segment are larger and directed anteriorly, while those on 3rd directed posteriorly. The posterior margin of the abdominal segments overlaps the next segment. Third, fourth and fifth segments bear a pair of lateral spines at their distal margin, which are directed towards the caudal region.

Telson (Fig.4.2I): Typical forked telson, each fork bearing a spine at its inner and outer margin. Inner margin of each fork bears three long serrated setae.

Second zoea (Fig.4.3 Plate 10 b).

Carapace length varies from 0.72 to 0.77 mm and abdomen-telson length from 1.46-1.54 mm. Eyes are stalked. Pair of medium short setae present on the dorsal surface of the first abdominal segment.

Antennule (Fig.4.4A): Number of aesthetes increased. On the distal side it bears five aesthetes and one setae.

Antenna (Fig. 4.4B): Elongated protopod two long rows of short spines as in the previous stage. Endopod bud has further developed. Exopod bears distally two unequal setae as in the previous stage.

Mandible (Fig.4.4C): More developed than the first zoeal stage and bears corrugated ridges of thickened cuticle.

Maxillule (Fig.4.4D): Coxal endite with six and basal endite with nine to ten setae which are sparsely setose. Endopod two segmented; proximal segment with single seta and distal segment with six setae.

Maxilla (Fig.4.4E): Coxal endite bilobed, each lobe carrying three setae. Each of the basal endites are with four to five setae. Endopod unsegmented bearing four terminal and two subterminal setae. Scaphognathite bear seven plumose setae along its outer margin. In addition to these the dorsally directed process bears three plumose setae.

First maxilliped (Fig.4.4F): Basipod broad bearing nine to ten setae along its inner margin. Endopod bears 2-2-0-2-5 setae counting from the proximal to distal segments. Exopod is with four long natatory plumose setae at its distal end.

Second maxilliped (Fig.4.4G): Basipod with three to four setae along its inner margin. Endopod bears 1-1-1-5-5 setae counting from the proximal segment. Exopod is with eight long plumose natatory setae at its distal region.

Abdomen (Fig.4.4H): Same as that of the previous stage, except for the development of a pair of medium setae on the dorsal surface of the first abdominal segment. Abdominal segments 3-5 have more distinct lateral spines.

Telson (Fig.4.4H): Developed a pair of short plumose setae at the inner median margin of the caudal furca. Other structures are same as that of the previous stage.

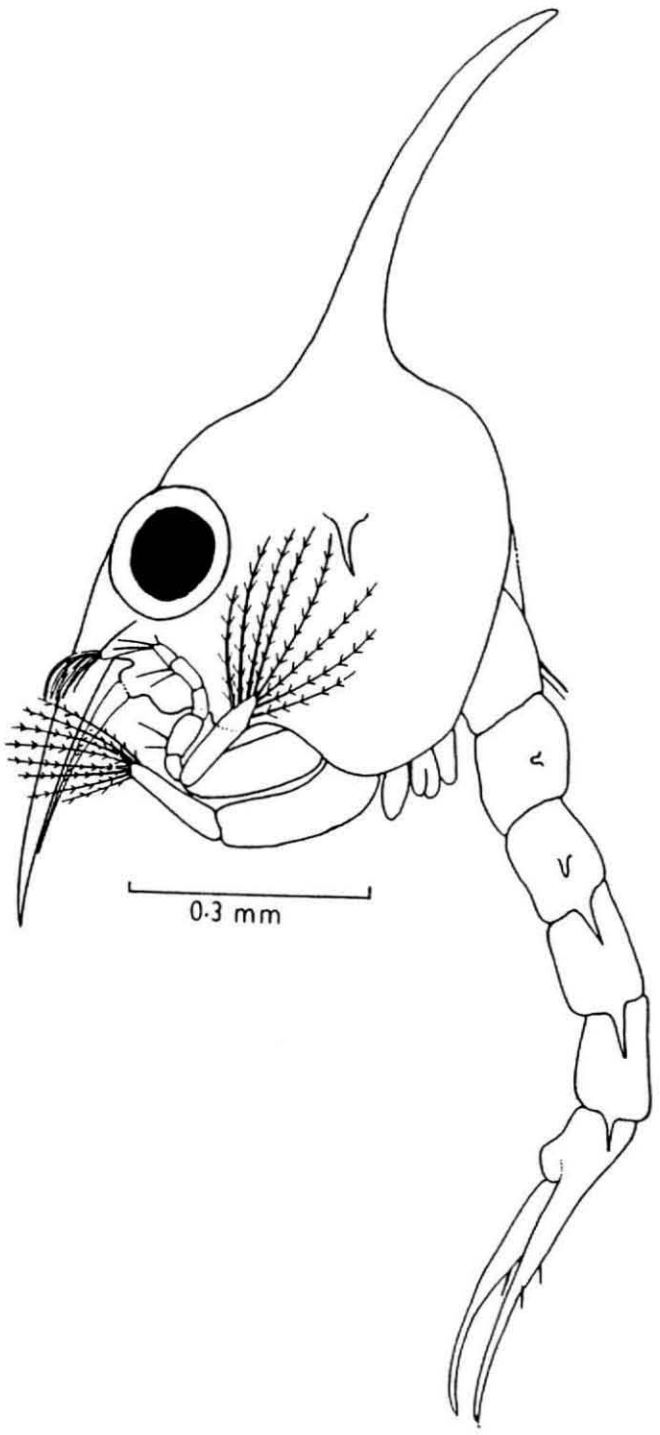


Fig. 4.3. ***Portunus pelagicus*** - Second Zoea .

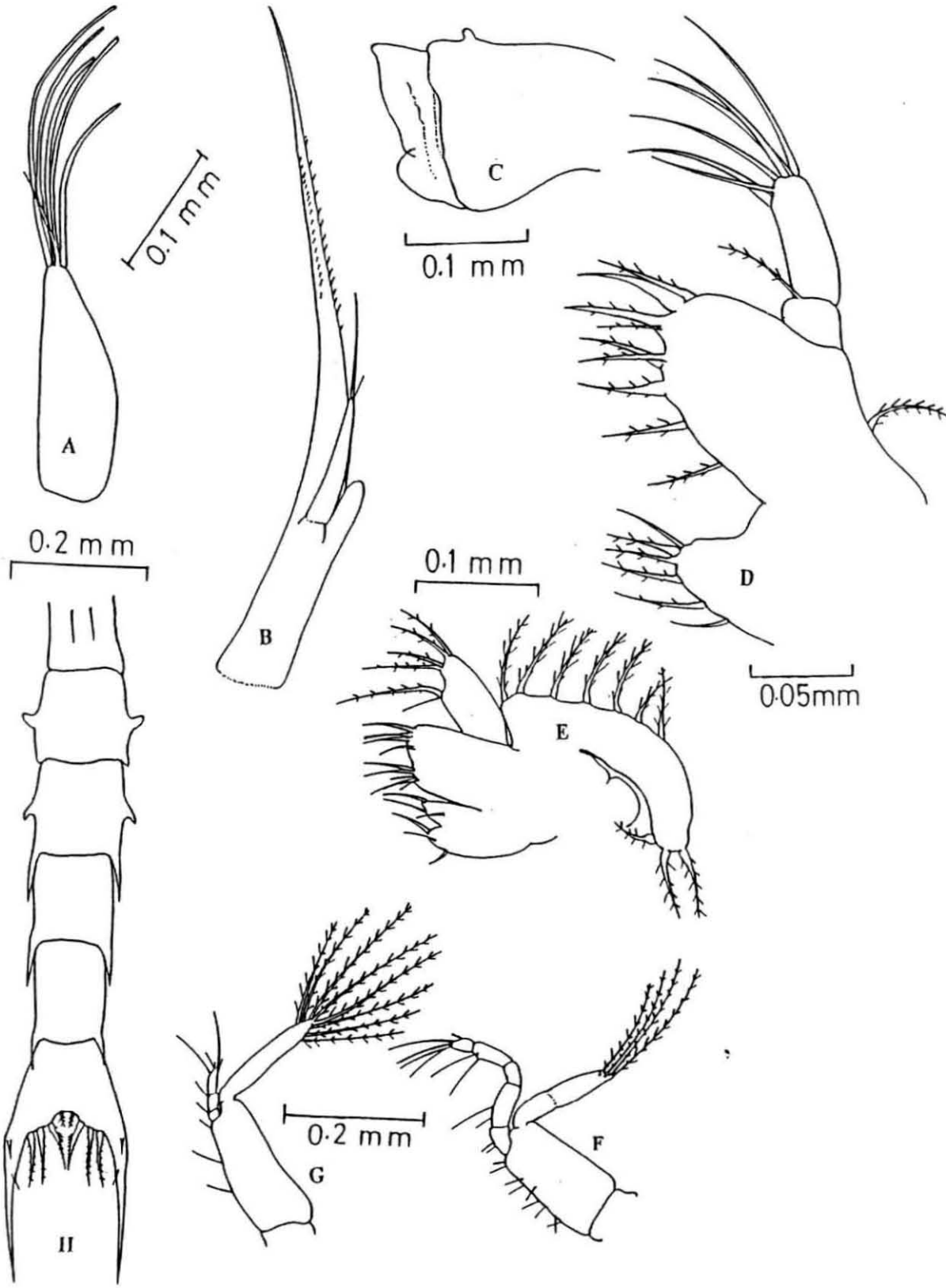


Fig. 4.4. ***Portunus pelagicus***. Appendages of second zoeal stages.
A, antennule; B, antenna; C, mandible; D, maxillule; E, maxilla; F, first maxilliped; G, second maxilliped; H, abdomen with telson.

Third zoea (Fig.4.5 & Plate 11 a).

Carapace length varies from 0.79 to 0.87 mm and abdomen-telson length between 2.02 to 2.21 mm respectively. Dorsal surface of the first abdominal segment has 3 median short setae. Rudimentary buds of the thoracic appendages are developed behind the second maxilliped (Fig.4.6h).

Antennule (Fig.4.6A): Antennule is as in zoea-II but larger. Aesthetes are arranged in two groups; a terminal and a sub-terminal group. The former consists of 4 long aesthetes and one seta and the latter 2 smaller aesthetes.

Antenna (Fig.4.6B): Has further developed, endopod has become as long as the exopod.

Mandible (Fig.4.6C): is as in zoea-II stage except that few prominent both developed on the cutting edges.

Maxillule (Fig.4.6D): Coxal endite bears 7 setae, of which few are setose. Basipod with 10 to 11 setae, of which, some are short and few are setose. Endopod two segmented. Distal segment is with 4 long terminal and 2 long sub-terminal plumose setae. Basipod of the maxillule bears two plumose setae on its outer margin.

Maxilla (Fig.4.6E): Each of the coxal endites bear 3 setae of which one is stout. Basal endites, each bear 4 to 6 setae of which some are setose. Scaphognathite further developed bearing 17-18 plumose setae at its outer margin.

First maxilliped (Fig.4.6F): Has become longer than that of the zoea-II stage. Exopod bears 4 long terminal and 1-2 long subterminal plumose natatory setae.

Second maxilliped (Fig.4.6G): Exopod with 4 long terminal and 5-6 long sub-terminal plumose natatory setae.

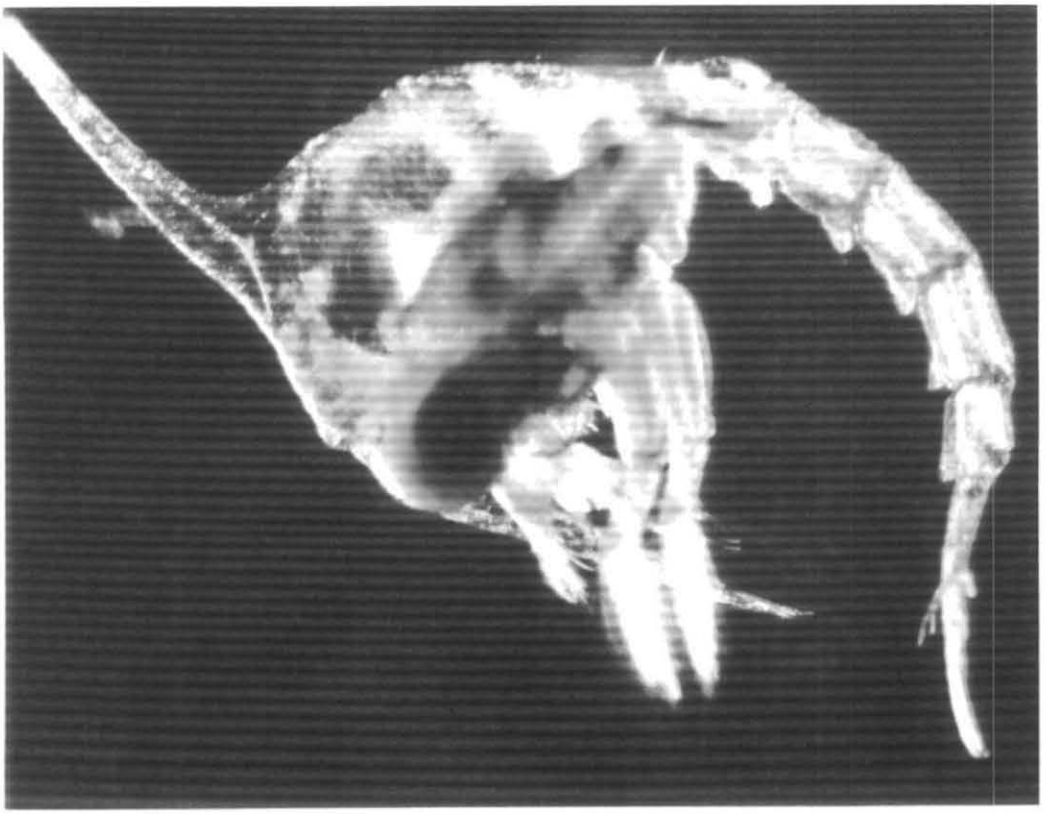
Abdomen (Fig.4.6I): Is 6 segmented and lateral spines on 3-5 segments longer. Abdomen develops paired pleopod buds at the ventral posterior end of the second to fifth segments.

Telson (Fig.4.6I.) Grows well distinct and other characters are same as that of the previous stage

Fourth zoea (Plate 11 b).

Carapace length varies from 0.98 to 1.06 mm and abdomen-telson length between 2.61 to 3.03 mm. Biramous bud of third maxilliped developed (Fig.4.7H).

Plate 11



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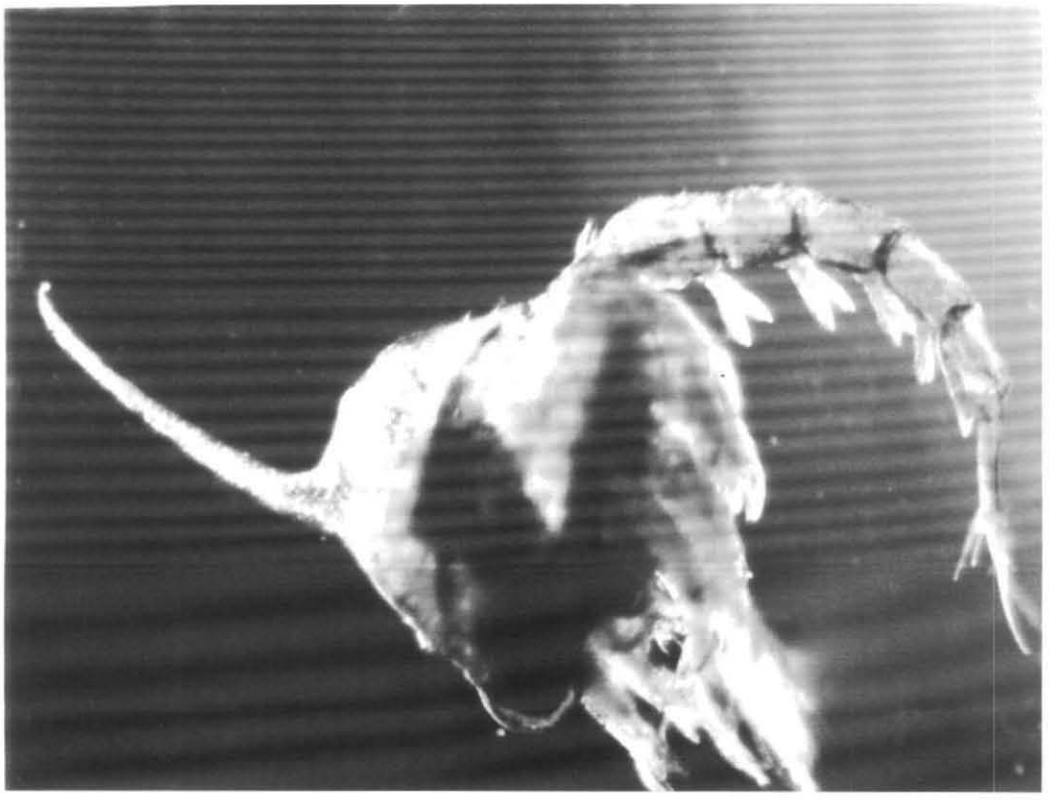


b

Larval stages

a. Zoea III (40x)

b. zoea IV (40x)

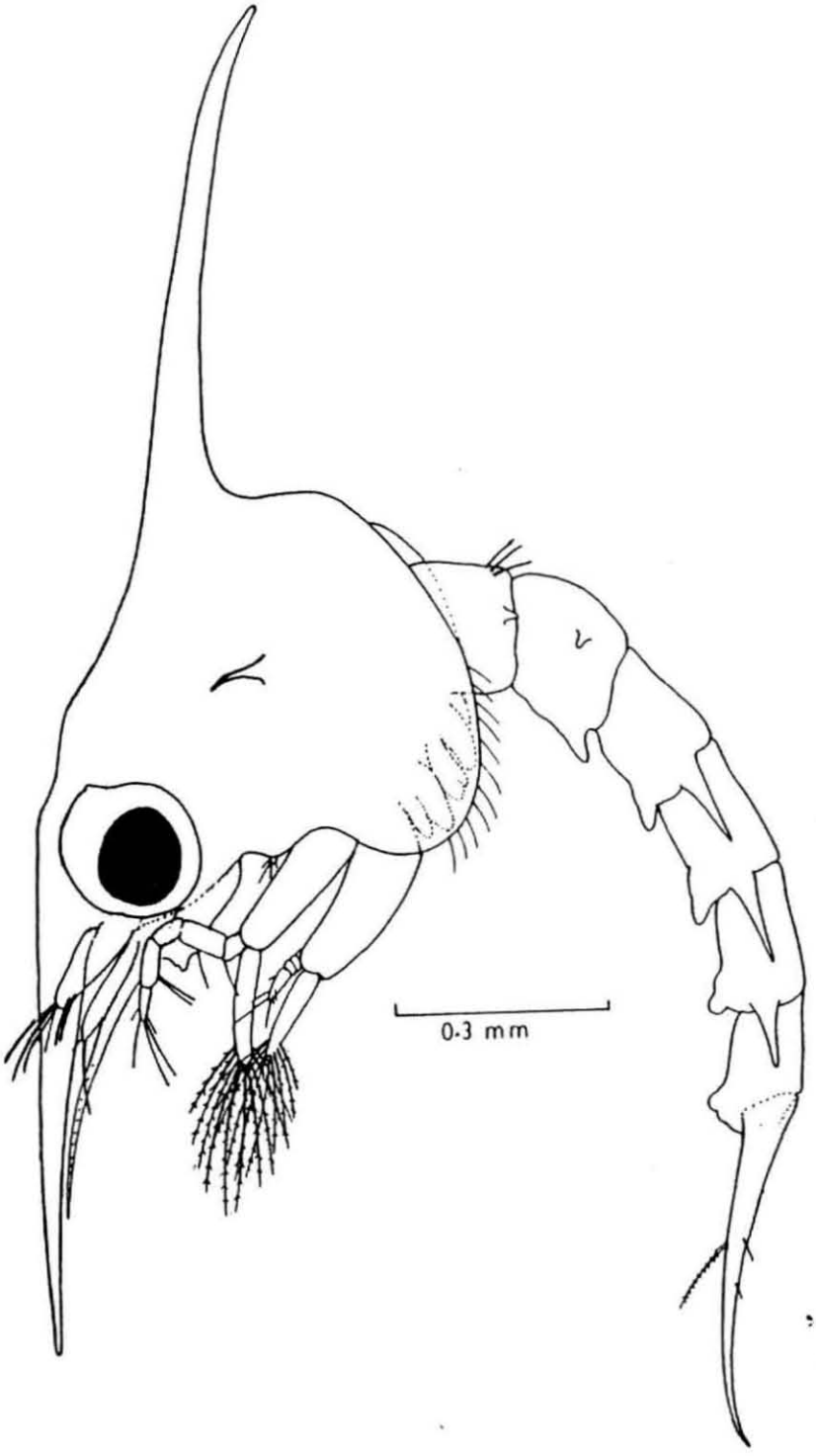


Fig. 4.5. ***Portunus pelagicus*** - Third Zoea.

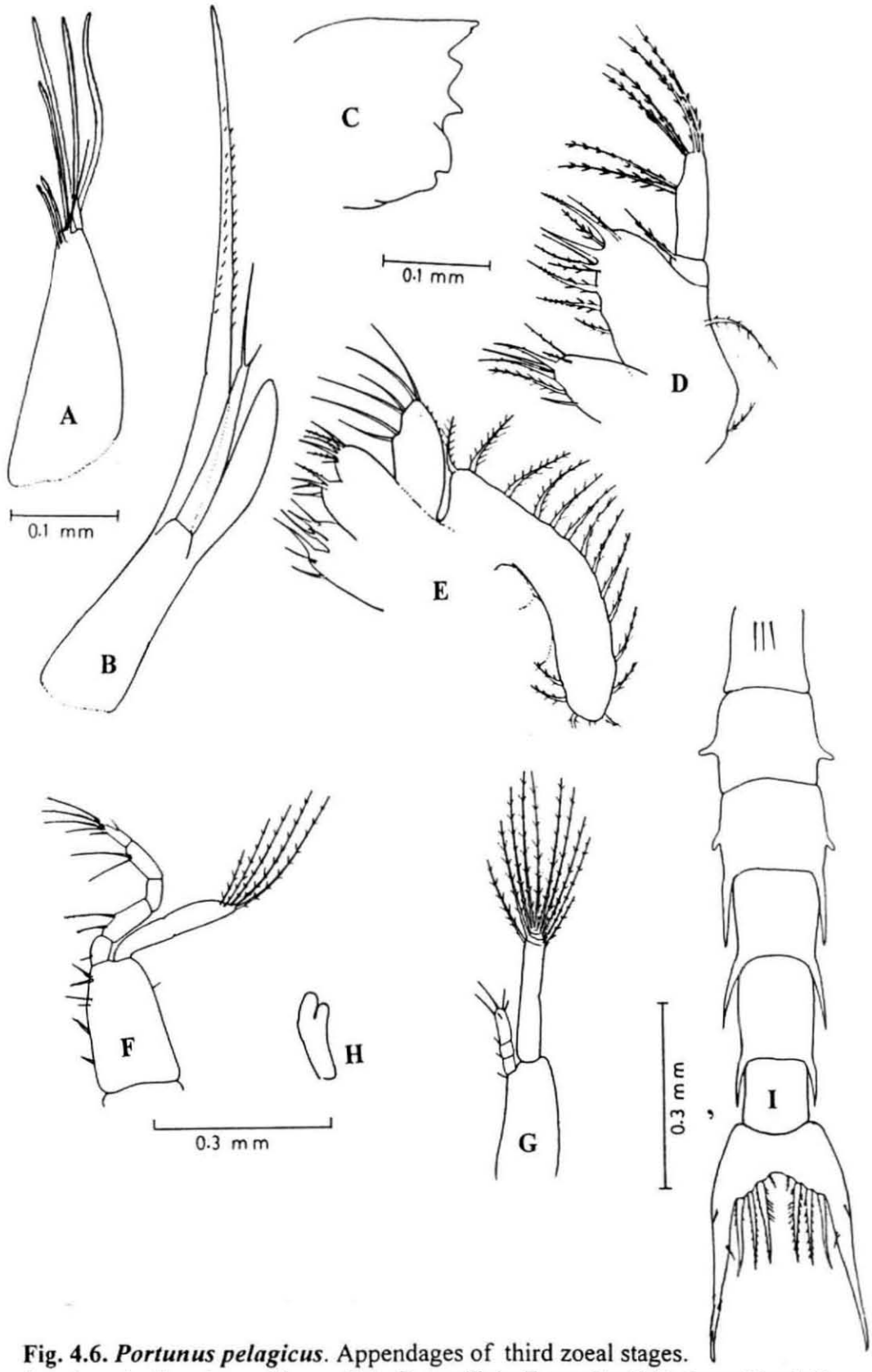


Fig. 4.6. ***Portunus pelagicus***. Appendages of third zoeal stages.
A, antennule; B, antenna; C, mandible; D, maxillule; E, maxilla; F, first maxilliped; G, second maxilliped; H, rudimentary thoracic appendage; I, abdomen with telson.

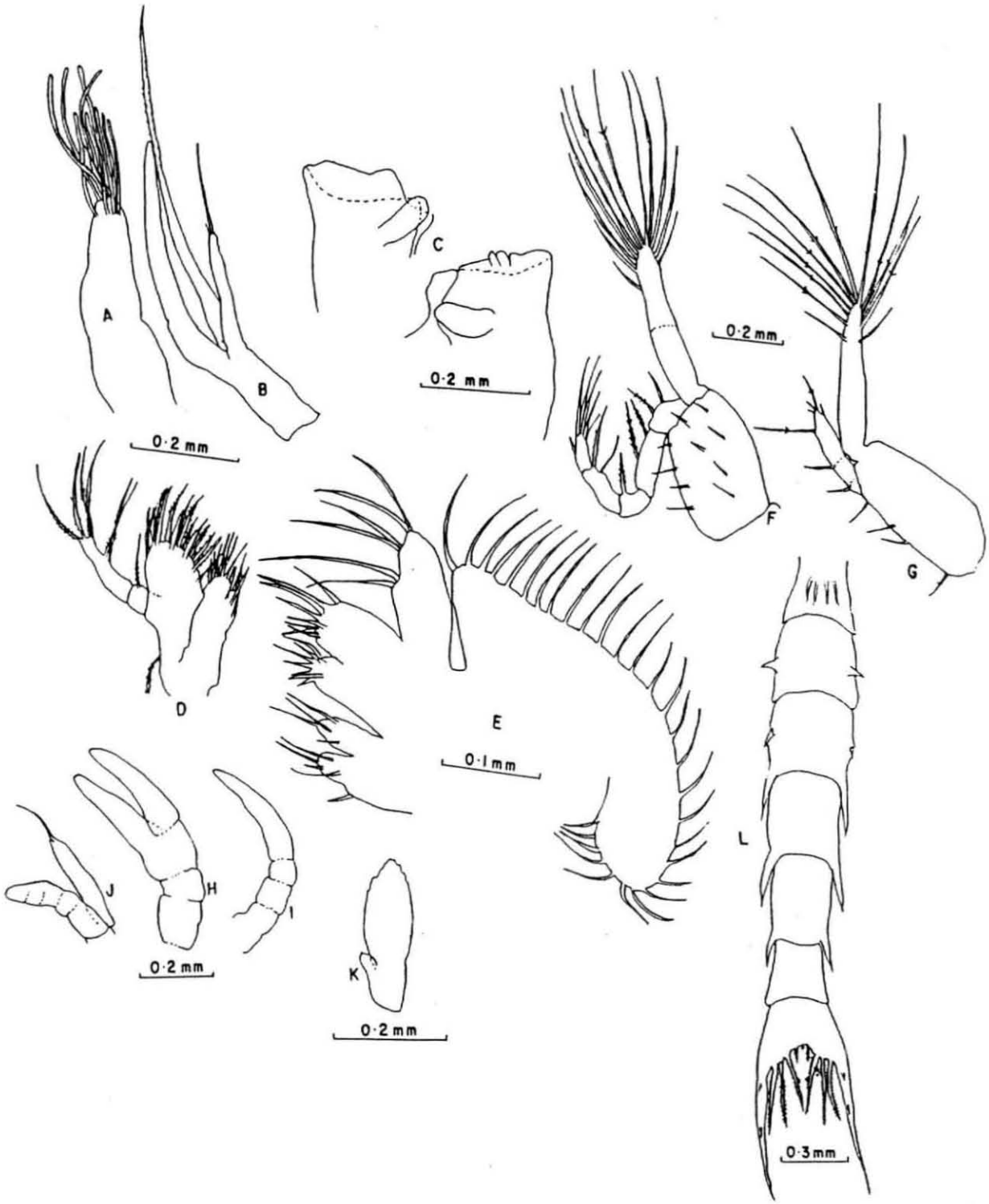


Fig. 4.7. ***Portunus pelagicus***. Appendages of fourth zoeal stages.
A, antennule; B, antenna; C, mandible; D, maxillule; E, maxilla; F, first maxilliped; G, second maxilliped; H, first pereiopod; I, second pereiopod; J, third pereiopod; K, second pleopod; L, abdomen with telson.

First pereiopod bud with well developed chela (Fig.4.7I). second to fifth pereiopod buds show signs of segmentation (Fig.4.7J). second to sixth pleopod bud developed (Fig.4.7K). Exopod of some pleopod buds are with short non-plumose setae. Dorsal surface of the first abdominal segment has 4 short setae in a median transverse row.

Antennule (Fig.4.7A): Bears aesthetes in two tiers. At the terminal end it bears 4 aesthetes and one seta. Next group of aethetes are placed sub-terminally. Development of endopod is indicated as a small bud.

Antenna (Fig.4.7B): Larger than that of the zoea III. Endopod has become longer than that of the exopod.

Mandible (Fig.4.7C): Size has increased than the previous stage. Mandibular palps indicated as small bud.

Maxillule (Fig.4.7D): Coxal endite with 12-13 setae and basal endite with 15-16 setae. Some of the setae on the basal endite are stout and sparsely setose. Distal segment of the two-segmented endopod is with 4 long terminal and 2 sub-terminal plumose setae. Proximal segment on the inner margin bears one plumose seta. Outer margin of the basipod carries two short plumose setae.

Maxilla (Fig.4.7E): Scaphognathite expanded bearing 30 to 32 plumose setae along its outer margin. Number of setae on the coxal and basal endites increased. Each of the coxal endite bears 4 to 5 setae and basal endites with 7-9 setae. Endopod carries six plumose setae of which two are placed on the inner margin towards the middle region.

First maxilliped (Fig.4.7F): Size has increased and endopod segments bearing 2-2-1-2-6 setae starting from ischium. Exopod has four long terminal and eight long plumose natatory sub-terminal setae.

Second maxilliped (Fig.4.7G): Except for the increase in the plumose setae other characteristics remain unchanged. Exopod bears terminally 4 and sub-terminally 8 long plumose natatory setae.

Abdomen (Fig.4.7L): Pleopod buds on abdominal segments 2 to 6 are well developed. They are large and biramous except for the fifth pair that is uniramous.

Telson (Fig.4.7L): All structures are similar to the Z-III except for the development of an additional short seta at the inner margin of caudal furca.

Megalopa (Fig.4.8A & Plate 12.a)

Megalopa are very similar to that of other portunids. Rostral spine present. Eyes project as far as the lateral margin of the carapace. Carapace length including the rostrum varied from 1.69 to 1.81 mm and the breadth 1.16 to 1.3 mm. Abdomen six segmented with dorsoventrally flattened telson. Abdominal length (including telson) varied from 1.31 to 1.35 mm. Total length including rostrum varied from 3.00 to 3.2 mm.

Antennule (Fig.4.9A): With 3-segmented peduncle and two ramii. Basal segment of peduncle is bulbous. Inner ramus unsegmented bears 3 distal and one inner lateral setae. Outer ramus 5 segmented proximal segment without setae or aesthetes. Second to fourth segments bearing 15-18 aesthetes arranged in 3 tiers. Distal segment bears two plumose setae.

Antenna (Fig.4.9B): Is elongated and 11 segmented. Proximal segments comparatively larger and bear simple setae. Eighth segment bears 4 setae on its distal margin. Distal segment is with 4 setae.

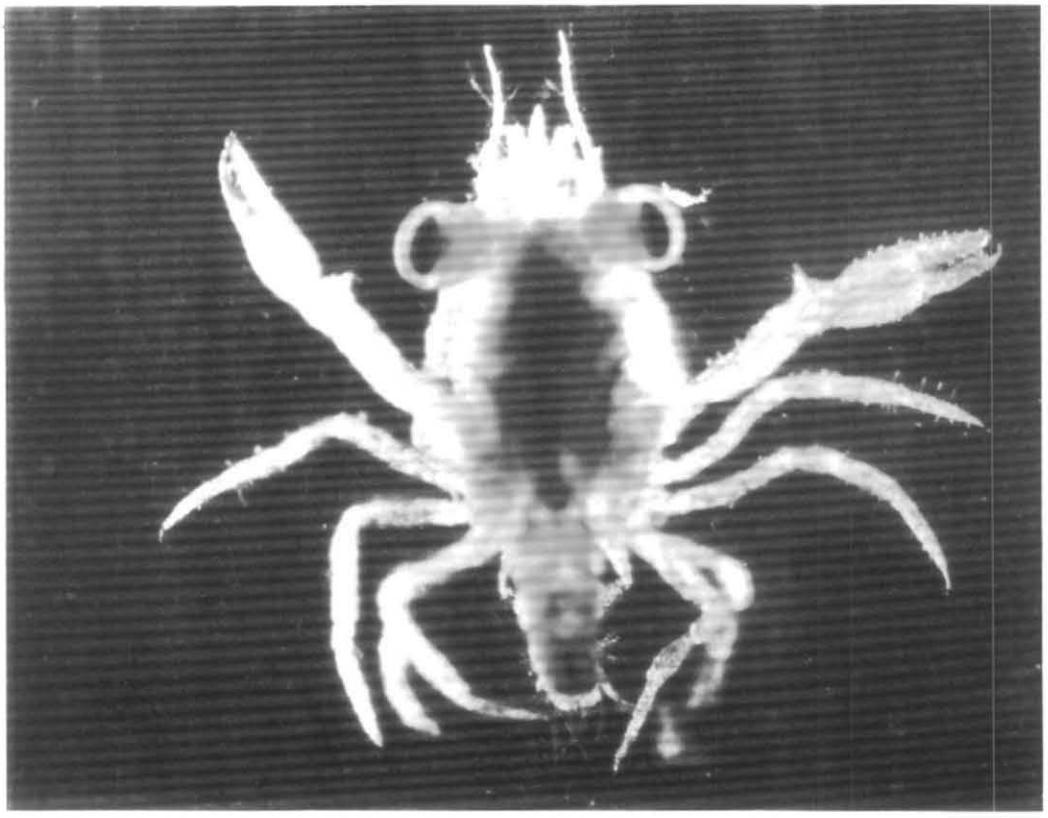
Mandible (Fig.4.8B): Is reduced to a simple cutting edge. Bears a 3 segmented palp. Distal segment of the palp is broader and carries 11 to 12 short plumose setae.

Maxillule (Fig.4.8C): Coxal and basal endites are unsegmented. Coxal endite bears 4-5 setae distally and 8-10 setae along the lateral border of which the inner lateral setae are relatively longer than the rest. Basal endite has 17-20 setae of which 5-7 are stout. Endopod 2-segmented. Proximal segment is with 3 and distal segment and 1 to 2 setae.

Maxilla (Fig.4.8D) : Both coxal and basal endites bilobed. Each lobe of the coxal endite bears 3-4 terminal and 1-3 lateral setae. Each of the basal endite carries 9 to 12 setae on which few are stout. Endopod reduced. Scaphognathite bears 58-60 plumose setae along its outer margin.

First maxilliped (Fig.4.9C): Coxal and basal endites unsegmented, both endites are expanded bearing a number of setae, which serve for mastication. Endopod unsegmented slightly expanded and bear 4 setae at its distal margin. Exopod 2 segmented and distal segment bears 5 terminal setae.

Plate 12



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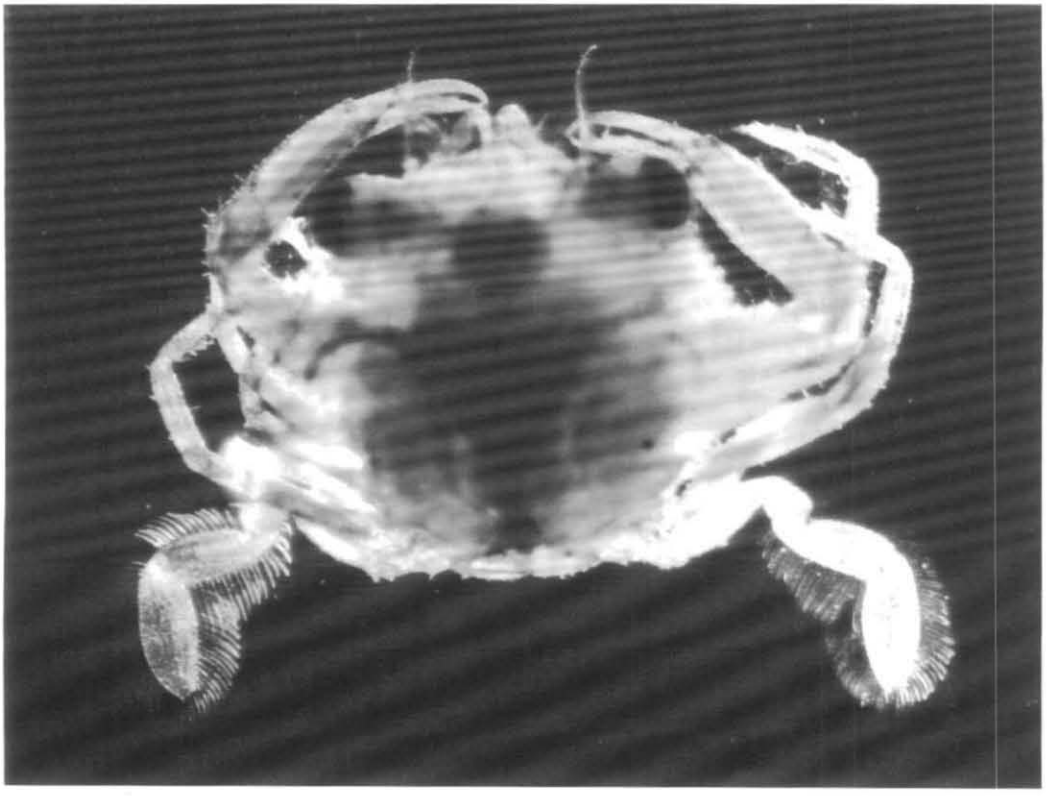


b

a. Megalopa (25x)

b. Crab instar -1 (25x)

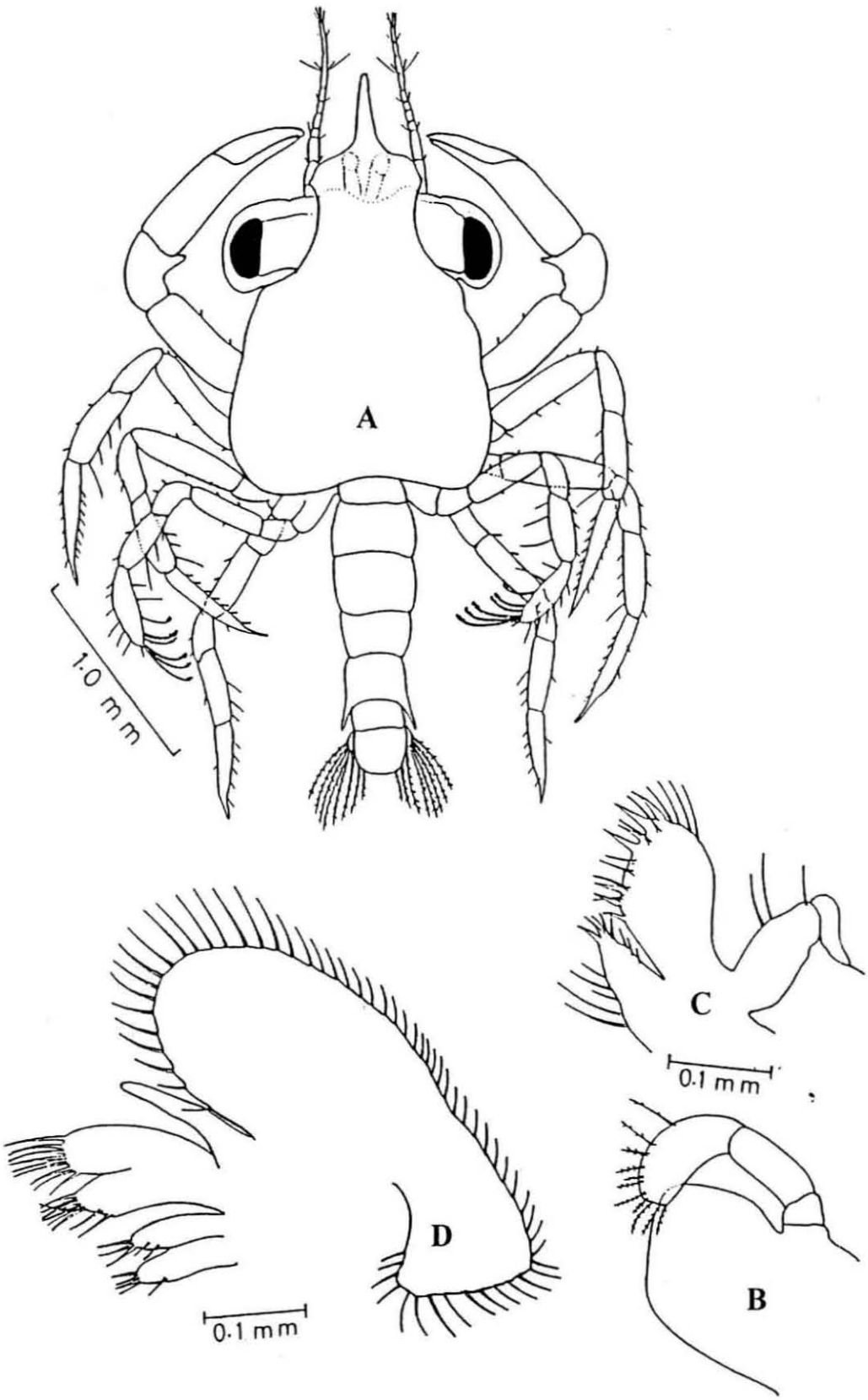


Fig. 4.8. ***Portunus pelagicus*** Megalopa and its appendages .
A, megalopa; B, mandible ; C, maxillule; D, maxilla.

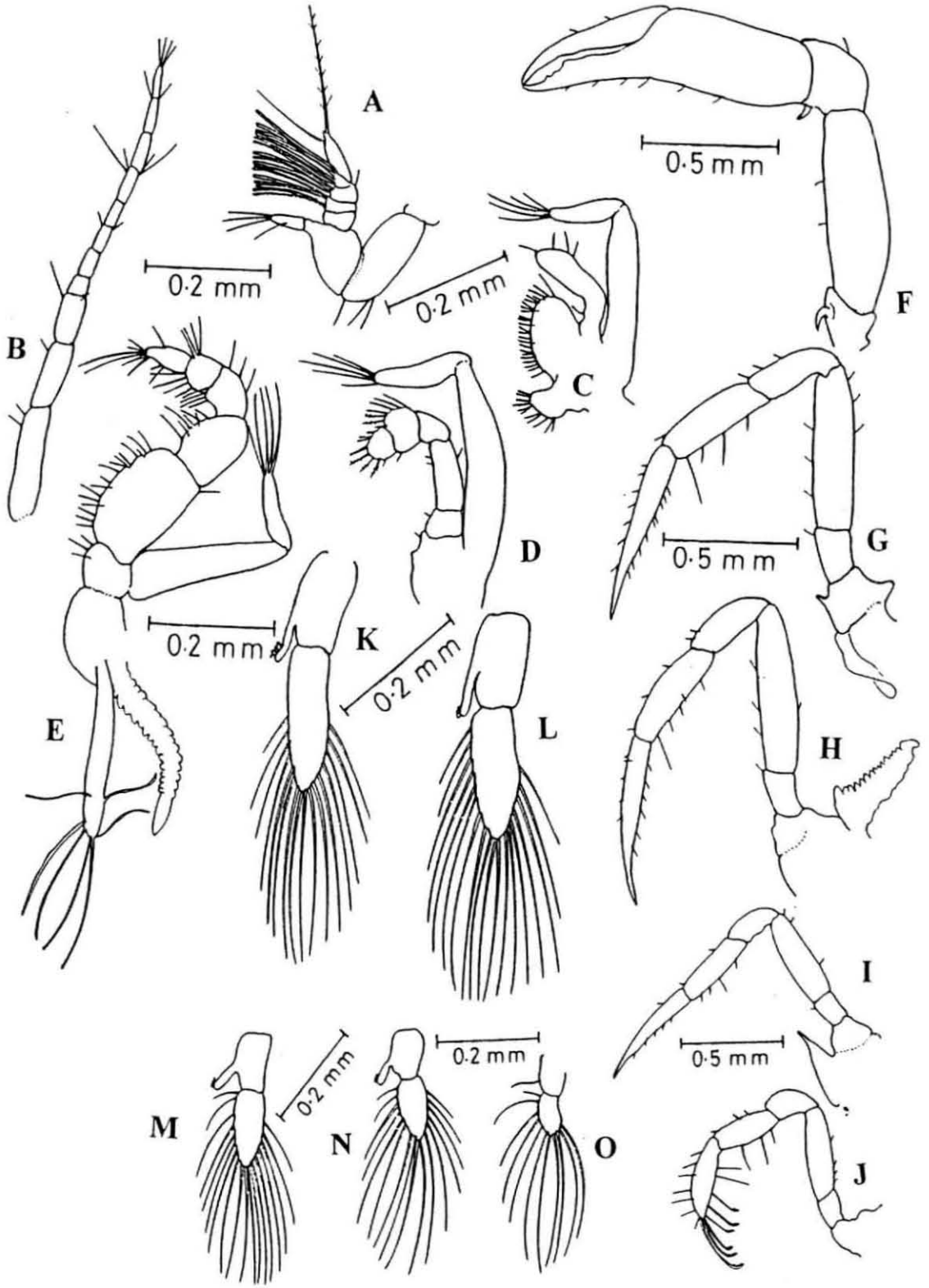


Fig. 4.9. ***Portunus pelagicus***. Appendages of the megalopal stage.
A, antennule; B, antenna; C, first maxilliped; D, second maxilliped; E, third maxilliped; F, first pereiopod; G, second pereiopod; H, third pereiopod; I, fourth pereiopod; J, fifth pereiopod; K-N, second to fifth pleopods; O, uropod.

Second maxilliped (Fig.4.9D): Endopod 5 segmented. Distal two segments have a flattened shape each bearing 7 to 10 setae respectively, of which some of them are stout and plumose. Exopod 2-segmented, distal segment smaller than the proximal bearing 5 terminal setae.

Third maxilliped (Fig.4.9E): Well developed. Endopod 5-segmented, first segment is more flattened bearing 16 to 18 and second segment 7 to 8 setae, respectively along its inner margin. Distal margin bears six setae (two of which are longer than the rest) at its distal margin and three setae sub-terminally. Exopod 2-segmented distal one longer than the proximal one bearing 5 to 6 terminal setae. Coxopod bears a well-developed epipodite and a gill.

First pereiopod (Cheliped) (Fig.4.9F): 5 segmented and well developed. All segments bear few short setae, their number is maximum on propodus. Ischium and carpus bear one short and stout spine.

Second to fifth pereiopods: They have well-developed endopods. Endopods have 5 segments. Basipod of the second pereiopod bears a spine on its inner surface (Fig.4. 9G). All segments of the endopod bear few short setae, their number is maximum on the last segment. One of the inner setae on the propodus of second and third pereiopods is longer than the rest, (Fig.4.9H) a character which is absent in the 4^{th} pereiopod (Fig.4.9I). Dactylus of the fifth pereiopod (Fig.4.9J) slightly flattened bearing at its distal inner margin 6 to 7 long, hooked, modified setae. Abdomen bears 5 pairs of pleopods.

Pleopods : First abdominal segment has no pleopods. second to fifth pleopods are almost similar in structure (Fig.4.9K to 9N). Exopods bear 15 to 20 plumose setae. Endopod is short bearing 3 to 4 modified setae distally. Uropod (Fig.4.9O) is uniramous, bearing 11 plumose setae. Basipod of the uropod bears one long setae at its inner margin.

Crab stage (Plate 12.b)

Megalopa metemorphoses to crab instar-1, the carapace width varied between 2.0-2.5 mm. It resembles an adult crab; margin of the carapace serrated with 9 anterolateral spines. Pereiopods well developed with setae, especially on the propodus and dactylus of the fifth pair of legs.

Growth in males and females

The males have grown from an initial average carapace width of 2.38 ± 0.18 mm to 159.86 ± 3.52 mm; *i.e.* from first instar to sixteenth instar within a mean period of 272 days and further reared to a maximum of 455 days. The average total weight gained was 275.00 ± 25.41 g from an initial weight of 0.008 g (Table 4.1).

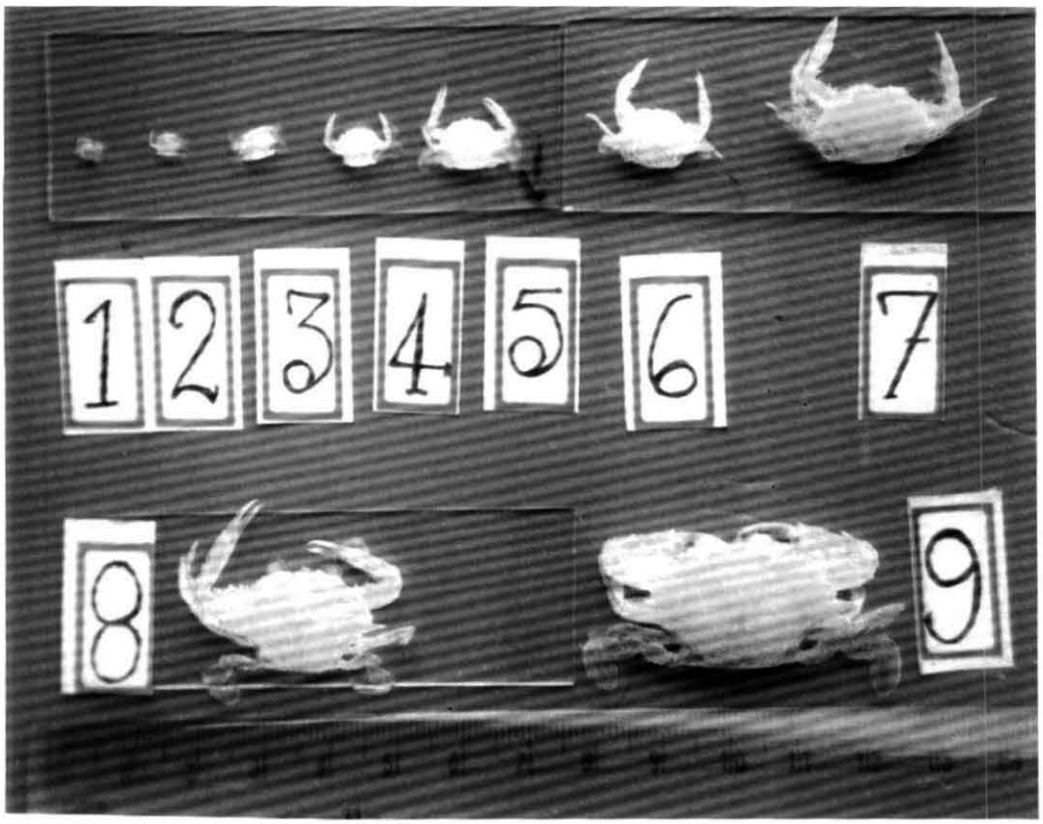
Females have grown from an initial average carapace width of 2.43 ± 0.34 to 154.31 ± 2.73 mm, reached sixteenth instar within a mean period of 332 days. The average weight gain during the same period was 0.006 g to 210.33 ± 18.39 g (Table 4.2 and plate 13,14).

In males the observations on the average growth increment in carapace width showed that moult increment was steadily increasing in the juvenile phase *i.e.* upto fourteenth moult and then decreasing. Almost same pattern of growth in carapace length was recorded till the fourteenth moult then it was fluctuating. The maximum percentage of carapace width increment occurred in its 1^{st} to 2^{nd} instar, 77.73% and lowest percentage during the 15^{th} to 16^{th} moult (13.06%). The carapace length increment showed highest percentage during its 11^{th} to 12^{th} moult (37.99%) and lowest during 14^{th} to 15^{th} moult, 11.12% (Table 4.3).

In females, the growth increment in carapace width was increasing till its 12th moult and then steady till 15^{th} moult and thereafter further decreased. Maximum percentage of increase in carapace width was recorded in its 1^{st} to 2^{nd} instar *i.e.* 68.72% and the lowest in 15^{th} to 16^{th} instar as in the case of males (10.78%). The moult increment of carapace length also shown same pattern as that of carapace width. Maximum percentage of carapace length increase was observed in its 8^{th} to 9^{th} instar stage (38.53%) and the lowest percentage in 15^{th} to 16^{th} moult, 9.17% (Table 4.4).

In crabs there are certain morphological features which are present in full expression at sexual maturity. These changes in morphological characters are otherwise known as secondary sexual characters, are prominent in both sexes of the crabs. In males, pubertal changes include the colour of the chelae and other pereiopods, length and depth of the pereiopods, and length of the first pleopods relative to the sternites in the sternal depression. In the present study, it was noticed

Plate 13



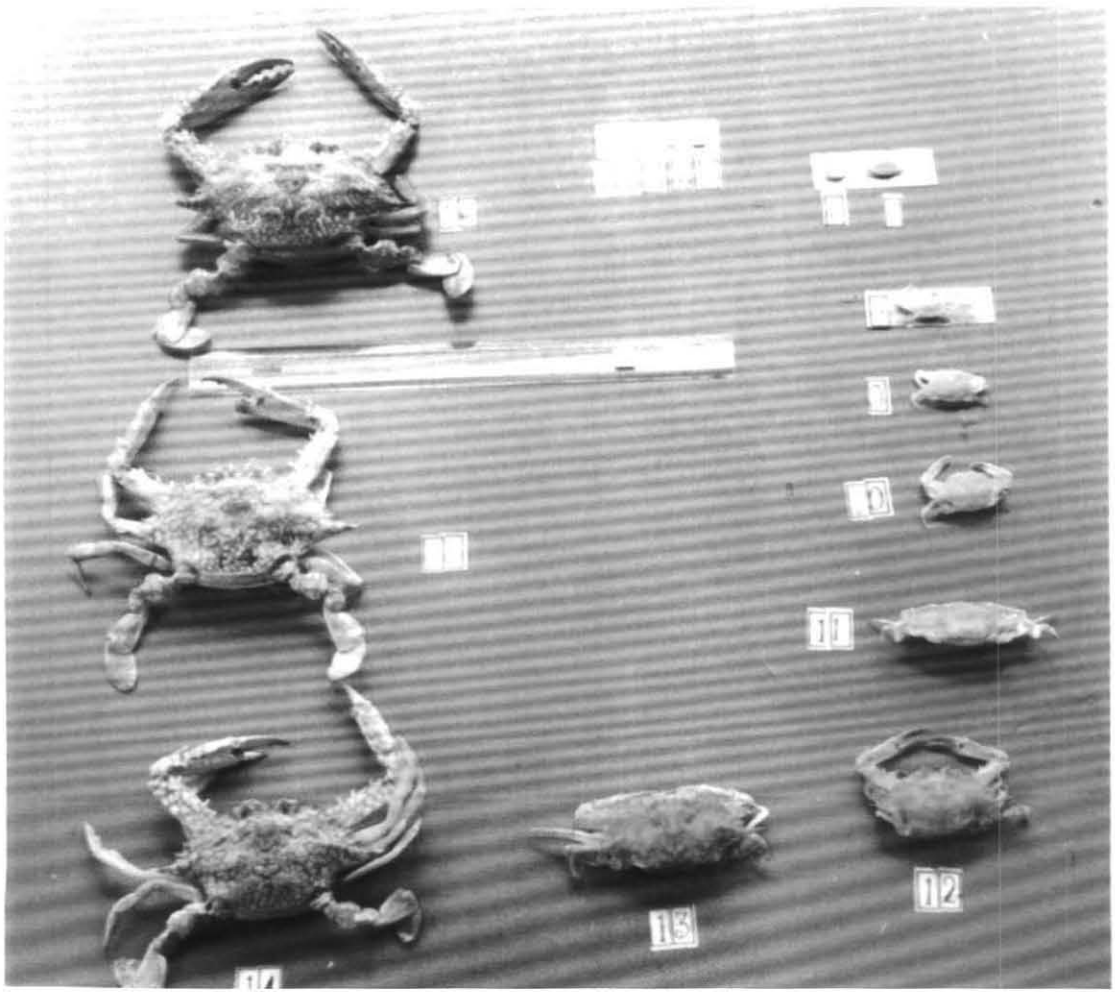
a

b

a. Moulted shells of 1 - 9 crab instar.

b. A groups of 2 weeks old baby crabs showing different pigmentation and colour pattern.

Plate 14



Moulted shells of 1 to 16 instars of *Portunus pelagicus* grown in the laboratory

Table. 4.1. GROWTH OF MALE *PORTUNUS PELAGICUS* IN THE LABORATORY

CRAB STAGE	MIN. DAYS FROM PRE. INSTAR	TOT.DAYS	MAX. DAYS FROM PRE. INSTAR	TOT.DAYS	AVERAGE DAYS FROM PRE.INSTAR	CARAPACE WIDTH (CW) mm	CARAPACE LENGTH (CL) mm	CHE. PROPODUS LENGTH (CPL) mm	CHE.PROPODUS DEPTH (CPD) mm	TOTAL WEIGHT (g)
1	0	0	0	0	0	2.38 ± 0.18	-	-	-	0.008
2	2	2	4	4	2.83 ± 0.76	4.23 ± 0.24	-	-	-	0.014
3	3	5	4	8	3.40 ± 0.55	5.13 ± 0.18	-	-	-	0.042
4	3	8	5	13	4.33 ± 1.03	6.55 ± 0.33	-	-	-	0.082
5	4	12	7	20	5.60 ± 1.14	9.10 ± 0.39	-	-	-	0.1
6	4	16	7	27	5.63 ± 1.19	12.13 ± 0.85	6.94±0.31	-	-	0.189
7	4	20	7	34	6.00 ± 1.15	16.63 ± 0.25	9.00±0.50	-	-	0.299
8	5	25	10	44	7.88 ± 1.73	23.17 ± 1.04	12.17±0.29	-	-	1.088±0.91
9	6	31	10	54	8.38 ± 1.41	33.86 ± 1.77	16.20±0.41	-	-	2.41±0.70
10	10	41	19	73	14.83 ± 3.31	46.38 ± 3.45	19.50±0.50	20.38±0.48	4.94±0.43	5.13±0.68
11	15	56	19	92	16.33 ± 1.51	60.80 ± 1.82	26.14±1.35	24.85±1.24	8.05±0.93	14.90±1.10
12	12	68	18	110	15.80 ± 3.11	82.25 ± 1.17	36.07±1.73	49.08±2.33	11.73±0.25	36.22±3.31
13	18	86	33	143	25.83 ± 5.42	99.01 ± 3.45	44.00±1.87	60.67±2.52	13.20±0.57	68.33±10.18
14	23	109	40	183	30.33 ± 6.53	122.13±3.50	56.50±1.91	84.50±1.38	17.18±0.96	123.14±4.74
15	33	142	74	257	50.67 ± 14.77	141.39±2.66	62.78±2.77	102.71±4.31	18.00±1.31	188.92±15.83
16	60	202	87	344	73.71 ± 8.96	159.86±3.52	72.22±2.99	121.56±2.96	20.91±4.12	275.00±25.41

Table. 4.2. GROWTH OF FEMALE *PORTUNUS PELAGICUS* IN THE LABORATORY

CRAB STAGE	MIN. DAYS FROM PRE. INSTAR	TOT.DAYS	MAX. DAYS FROM PRE. INSTAR	TOT.DAYS	AVERAGE DAYS FROM PRE.INSTAR	CARAPACE WIDTH (CW) mm	CARAPACE LENGTH (CL) mm	ABDOMEN WIDTH (AW) mm	ABDOMEN LENGTH (AL) mm	TOTAL WEIGHT (g)
1	0	0	0	0	0	2.43±0.34	-	-	-	0.006
2	2	2	4	4	2.83±0.75	4.10±0.14	-	-	-	0.01
3	3	5	5	9	3.80±0.84	5.20±0.25	-	-	-	0.024
4	3	8	5	14	3.83±0.75	6.58±0.57	-	-	-	0.075
5	4	12	7	21	5.80±1.09	9.62±1.10	5.40±0.29	-	-	0.099
6	4	16	7	28	5.60±1.79	13.40±0.60	7.25±0.25	-	-	0.177
7	4	20	8	36	6.20±1.79	17.20±1.20	9.38±0.14	-	-	0.32
8	6	26	9	45	7.00±1.22	24.27±2.06	12.25±0.32	-	-	1.44±0.32
9	7	33	10	55	8.80±1.30	33.33±3.78	16.97±1.44	-	-	2.43±0.50
10	10	43	18	73	14.0±3.54	48.00±4.76	22.30±1.26	9.63±0.95	14.13±1.31	5.98±0.72
11	14	57	19	92	16.6±2.07	62.88±3.57	27.63±2.29	15.13±1.93	17.88±2.25	15.63±1.70
12	12	69	22	114	16.0±2.92	85.50±6.75	36.20±3.46	20.50±0.71	24.13±2.59	32.22±2.85
13	17	86	34	148	25.2±6.66	101.78±2.78	44.11±2.15	25.07±3.12	30.56±3.01	64.33±7.50
14	28	114	47	195	36.4±7.37	120.43±2.23	51.83±1.17	34.88±3.71	37.00±1.15	106.50±9.94
15	45	159	101	296	68.2±21.04	139.29±1.81	62.50±1.16	42.75±1.76	47.28±2.17	150.50±2.90
16	98	257	129	425	112.0±11.89	154.31±2.73	68.23±2.01	50.73±1.38	55.86±2.22	210.33±18.39

Table. 4.3. GROWTH INCREMENTS IN LABORATORY REARED MALE *PORTUNUS PELAGICUS*.

CRAB STAGE	AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT	
	CW (mm)	%	CL (mm)	%	CPL (mm)	%	CPD (mm)	%	TW (g)	%
1	-	-							-	-
2	1.85	77.73							0.006	75.00
3	0.90	21.28							0.028	200.00
4	1.42	27.68							0.040	95.24
5	2.55	38.93							0.018	21.95
6	3.03	33.30							0.089	89.00
7	4.50	37.10	2.06	29.68					0.110	58.20
8	6.54	39.33	3.17	35.22					0.789	263.88
9	10.69	46.14	4.03	33.11					1.322	121.51
10	12.52	36.98	3.30	20.37					2.720	112.86
11	14.42	31.09	6.64	34.05	4.47	21.93	3.11	62.96	9.770	190.45
12	21.45	35.28	9.93	37.99	24.23	97.51	3.68	45.71	21.320	143.09
13	16.76	20.38	7.93	21.99	11.59	23.61	1.47	12.53	32.110	88.65
14	23.12	23.35	12.5	28.41	23.83	39.28	3.98	30.15	54.810	80.21
15	19.26	15.77	6.28	11.12	18.21	21.55	0.82	4.77	65.780	53.42
16	18.47	13.06	9.44	15.04	18.85	18.35	2.91	16.17	86.080	45.56

CW- Carapace width; CL- Carapace length; CPL- Chelar propodus length; CPD- Chelar propodus depth; TW-Total weight

Table. 4.4.GROWTH INCREMENTS IN LABORATORY REARED FEMALE *PORTUNUS PELAGICUS*.

CRAB STAGE	AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT		AVERAGE GROWTH INCREMENT	
	CW (mm)	%	CL(mm)	%	AW(mm)	%	AL(mm)	%	TW (g)	%
1	-	-	-	-	-	-	-	-	-	-
2	1.67	68.72	-	-	-	-	-	-	0.004	66.67
3	1.10	26.83	-	-	-	-	-	-	0.014	140.00
4	1.38	26.54	-	-	-	-	-	-	0.051	212.50
5	3.04	46.20	-	-	-	-	-	-	0.024	32.00
6	3.78	39.29	1.85	34.26	-	-	-	-	0.078	78.79
7	3.80	28.36	2.13	29.38	-	-	-	-	0.143	80.79
8	7.07	41.10	2.87	30.60	-	-	-	-	1.120	350.00
9	9.06	37.33	4.72	38.53	-	-	-	-	0.990	68.75
10	14.67	44.01	5.33	31.41	-	-	-	-	3.550	146.09
11	14.88	31.00	5.33	23.90	5.50	57.11	3.75	26.54	9.650	161.37
12	22.62	35.97	8.57	31.02	5.37	35.49	6.25	34.96	16.590	106.14
13	16.28	19.04	7.91	21.85	4.57	22.29	6.43	26.65	32.110	99.66
14	18.65	18.32	7.72	17.50	9.81	39.13	6.44	21.07	42.170	65.55
15	18.86	15.66	10.67	20.59	7.87	22.56	10.28	27.78	44.000	41.31
16	15.02	10.78	5.73	9.17	7.98	18.67	8.58	18.15	59.830	39.75

CW - Carapace width; CL- Carapace length; AW - Abdominal width; AL- Abdominal length; TW - Total weight

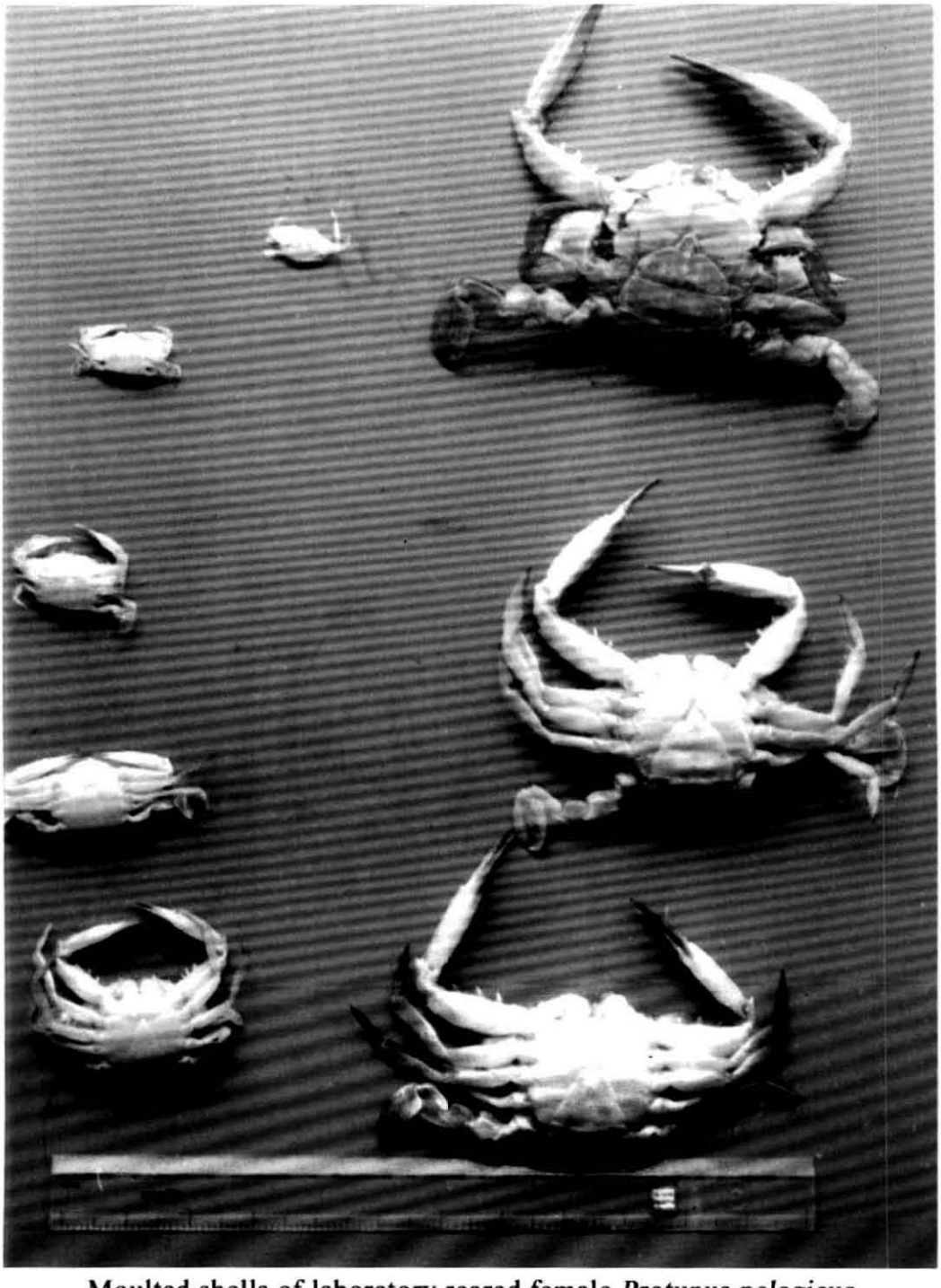
that there is a drastic change in the length of chelae in males by their 12th moult. The total increment was 24.23 mm from the previous moult registering 97.51% increase in chelar propodus length. Chelar propodus depth also increased, 3.68 mm (45.71%), but it was more prominent in the subsequent mature moultings. Male has pleopods modified as copulatory organ on the first and second abdominal somites.

Onset of sexual maturity was explicit in female crabs too. In contrast to males, passage of a female through pubertal moult was indicated by gross morphological changes particularly of the abdomen and accessory reproductive structures. The most evident change in the female was the change of the triangular abdomen to oval shaped one and in later moultings it almost attained a semicircular shape (Plate,15). In juveniles, abdomen was held tightly against the sternum and by the puberty moult the abdominal flap become free. All the abdominal segments become freely articulated and bordered by small setae. If the abdomen of the female was lifted, round oviduct openings can be seen which was a slit like in a juvenile crab. There are four pairs of biramous pleopods on the second to fifth abdominal segments and these pleopodal endopodites bear clusters of long and silky setae to which eggs are attached during spawning.

Another interesting observation in female puberty moult was the peculiar colouration on the dorsal surface of the abdomen. When a female approaches its puberty moult or moult from one mature instar to the next, the dorsal surface of the abdomen attains a bluish brown colour that persists for 3 to 4 days. This colour gradually disappears as the principal layer of the exoskeleton becomes calcified fully and abdomen changes to white colour similar to its other white under surfaces. This bluish brown colour was also seen associated with its pre-pubertal moult but not prominent as in pubertal moult. It gives an indication that the next moult of the animal will be the maturation moult. In the present study, abdominal width increment was 9.81 mm (39.13%) during the maturation moult. Maximum abdominal length was increased during its 15th moult *i.e.* 10.28 mm (27.78%).

In males the weight increment was steadily increasing after each moulting. Maximum percentage of weight increment was in their 7th to 8th moult (263.88%) and minimum during 4th to 5th moult (21.95%). In females too, the weight increment was

Plate 15



Moulted shells of laboratory reared female *Protunus pelagicus* showing increase in the abdominal width during subsequent moultings.

in an increasing manner and the maximum and minimum percentage of increase was recorded during 7th to 8th moult (257.50%) and 4th to 5th moult (32.00%) respectively. In general, the percentage of growth decreased after maturity particularly in female crabs.

Moulting and copulation

In advanced premoult period, crab's interest towards feeding was very less and feeding has stopped one or two days prior to moulting. It was observed that crabs become very passive and remain hidden for most of the time. Moulting commences with rupture of the carapace along the epimeral line, from the back towards the mouth of the crab. Actual active emergence from the carapace takes less than 5 minutes, the process has been observed directly in few of the juveniles during early morning hours. But this duration increases with increasing size of the crab. Body growth takes place after few hours of moulting. The moulted crabs take enormous quantities of water and stretched their body to the new expanded size. The exoskeleton hardens and become normal after 3-4 days. From the second day of the moulting they start feeding and feeding rate is more for the next 8-10 days.

In *Portunus pelagicus* as in other portunid crabs, copulation takes place only when the female is in the soft condition, with hard male. The male crab carries the female underneath the male and firmly held by the third and fourth walking legs, this pair formation usually starts 3-4 days before females moulting. Copulation occurs during night hours as soon as the female is moulted. In the presence of the female, the male crab becomes very active. Moving towards the female, the male grab her with one of his chelae, vigorously turn her over, draw her ventral surface towards his and finally mount her and male would insert his abdomen under that of the female. During copulation the male often walked around with the female still attached to its ventral surface, holding her with third and fourth walking legs. However, soon after the copulation the male generally gets burried himself and the female, with only their eyes protruding above the sand. Actual duration of the copulation is only few seconds, but the pairing will be continued for several hours or one or two days. Females would be inactive till they attain normal hardness to the exoskeleton.

In many cases of mating it was observed that pre-copulatory activities started

many days before the female moulting. After mating, in most cases, the pair was separated after few hours or within a day. In one instant (male – 130 mm/200 g: female – 124 mm/110 g) "pre-copulatory embrace" lasted for eight days and the 9th day only female moulted and the same day they have separated. The pair did not show any interest in feeding with occasional movements in the tank, carrying the female with one or two pairs of pereiopods or with chelate legs. It was also seen competition and fight among male crabs for catching a female.

Spawning and incubation

During the present study a total of 24 spontaneous spawnings were observed in the experimental crabs. The spawning occurred within a period of 15-26 days after the copulatory moults during night hours. The mean duration was 18.6 ± 4.83 days. The intervals between moulting and spawning are given in the following table.

Sl.no	Interval between moult/spawning	Day
1.	First maturation moult and first spawning	18.6 ± 4.83
2.	Final spawning in first maturation moult cycle and second moult of maturation	30.0 ± 16.54
3.	Second moult of maturation and spawning	25.0 ± 12.78
4.	First and second spawning	25.4 ± 4.24
5.	Second and third spawning	20.0 ± 4.00

The female crabs were capable of multiple spawnings and spawned a maximum of 3 times during an intermoult cycle. In very few cases, no spawning was observed in the first intermoult period after the first maturation moult. But the same crabs readily spawned after their second maturation moult; in one case it was a gap of 20 days in another after 26 days and a maximum of 2 spawnings in the cycle.

The newly spawned eggs are bright yellow and there does not seem to be any definite number of eggs attached to each seta of the pleopod. The eggs are spherical and surrounded by two membranes, an inner and outer membrane. Both membranes are transparent and the yolk is visible as yellow granules with polygonal areas. Owing to the large size of the egg mass the abdomen is almost straight, continuos with the

cephalothorax and the telson is slightly tilted upwards. The berried females were able to burry themselves in the sand and at very few occasions only they came out and moved freely in the tank. There were few cases in that the animal could not complete its embryonic development and aborted its eggs in between or at the end of the incubation period without hatching the zoeae. Fecundity ranged between 60,000 and 13,25,000 with an average number of 5,44,782. The details of spawning is given in table 4.5.

The newly oviposited eggs contain all the necessary material for synthetic processes associated with embryogenesis and morphogenesis and all of the compounds required for oxidative metabolism and energy production. The egg contains nutritive reserves in the form of proteinaceous yolk and lipid vesicles scattered throughout the cytoplasm. The newly spawned eggs are bright yellow as the yolk contains carotenoid pigments. As the development progresses the bright yellow colour changes to dull yellow and finally to dark grey just one day before hatching (Plates-16,17). At this stage, under the microscope one could see the developing larvae with its occasional twitching movements. During this period there is considerable increase in the egg size also. The following table gives the egg sizes during the course of egg development.

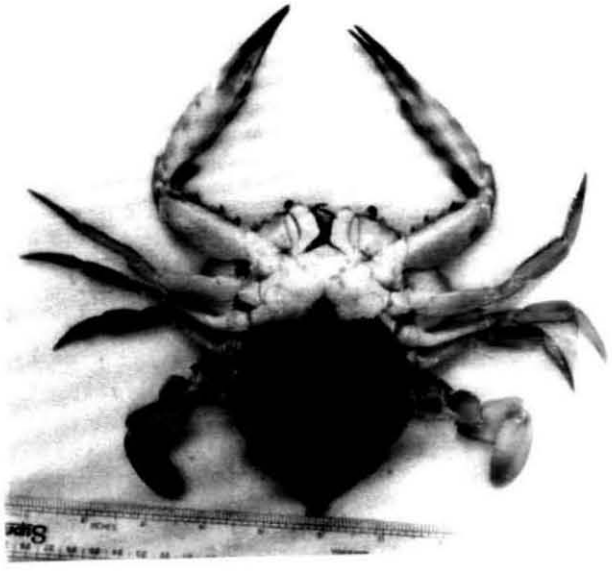
Stage	Egg colour	Size range (μ)
I	Bright yellow	336.40 ± 37.70
II	Dull yellow	366.78 ± 11.53
III	Dark grey	428.33 ± 22.33

The total days of incubation varied between 8-10 days, with a mean value of 9.25 ± 0.79 days. The incubation days taken by different mother crabs are given in the table 4.5. It has been observed that the incubation time taken by the same crab varied during one intermoult period. From the change of berry colour the hatching day assumed and the particular animal was separated for hatching.

Plate 16

a

b

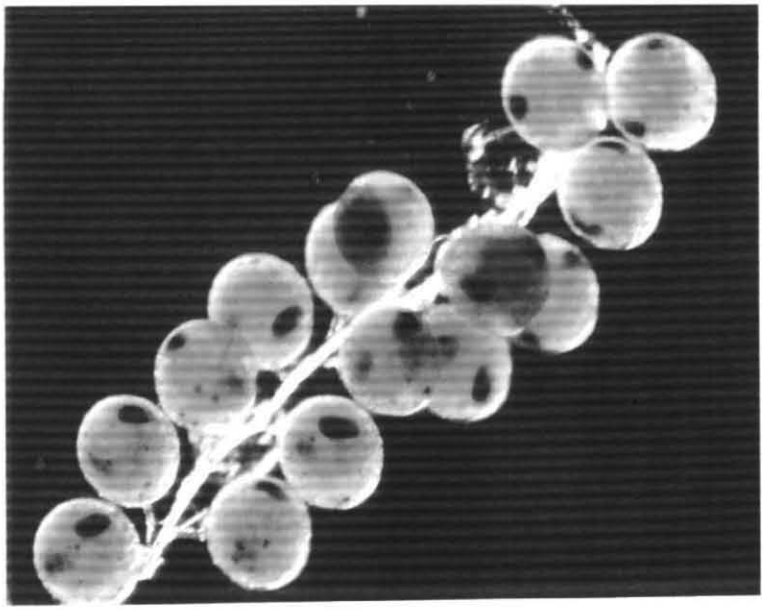


c

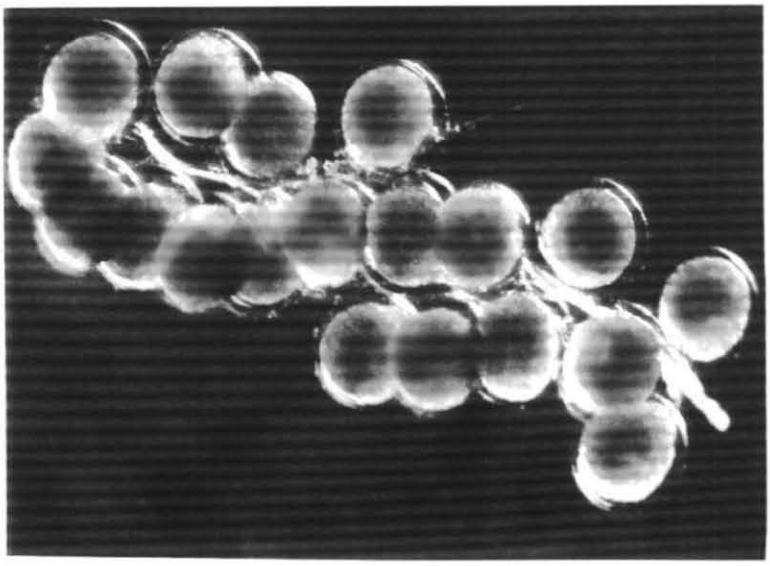
Egg mass of ovigerous females in different stages of embryonic development

a. Stage 1 b.Stage 2 c.Stage 3

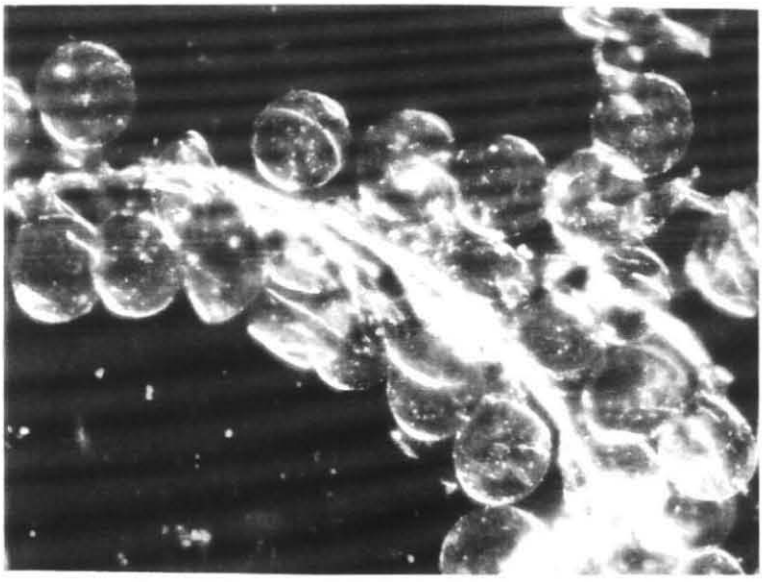
Plate 17



a



b



c

Eggs attached to pleopodal setae in different stages of embryonic development.

a. 8 days before hatching (50 x) b. 2 days before hatching (40x)

c. hatched egg shell (40x)

Table. 4.5.DETAILS OF SPAWNING IN THE LABORATORY REARED *PORTUNUS PELAGICUS*

NO.	SIZE OF THE CRAB CW(mm) / TW (g)	SPAWNING INTERVALS	TOTAL EGGS PRODUCED	INCUBATION DAYS
1	a) 110/ 80----------1	1 spawning after 15 days of maturation moult.	60000	9
	Moulted after 30 days of previous spawning.			
	b)130/125---------11	1 spawning after 17 days of moulting.	640000	10
		2 spawning after 26 days.	725500	9
2	a) 121/100--------1	1 spawning after 15 days of maturation moult.	90000	10
	Moulted after 34 days of previous spawning.			
	b) 134/150--------11	1 spawning after 15 days of moulting.	452000	9
		2 spawning after 26 days	684000	aborted eggs after 5 days.
		3 spawning after 16 days	339000	8
3	a) 122/105---------1	1 spawning after 21 days of maturation moult.	129500	10
		2 spawning after 29 days.	370000	9
		3 spawning after 24 days.	352200	8
	Moulted after 10 days of previous spawning.			
	b) 137/145---------11	1 spawning after 25 days of moulting.	643000	9
		2 spawning after 21 days.	1015000	10
4	a) 123/110---------1	1 spawning after 16 days of maturation moult.	812000	10
	Moulted after 42 days of previous spawning.			
	b) 139/150---------11	1 spawning after 21 days of moulting.	525000	10
		2 spawning after 27 days	415000	9
5	a) 129/110---------1	1 spawning after 26 days of maturation moult.	255600	8
		2 spawning after 19 days.	275000	10
		3 spawning after 20 days	300000	10
	Moulted after 12 days of previous spawning.			
	b) 148/160---------11	1 spawning after 22 days of moulting.	925000	9
		2 spawning after 23 days.	765500	10
6	* 136/120----------1	1 spawning after 26 days of previous moulting.	455000	Died on the 10th day of incubation
7	* 138/155----------1	1 spawning after 20 days of previous moulting.	831460	9
		2 spawning after 32 days.	690000	10
	Moulted after 52 days of previous spawning.			
	b) 159/250--------11	1 spawning after 50 days of previous moulting.	1325000	Died on the 7th day of incubation

* No spawning in the intermoult period after the maturation moult.

Hatching

In most of the cases nocturnal hatching of eggs has been observed and rarely during morning hours. When the larvae are about to hatch, the eggs are liberated from the pleopods by a conscious effort of the mother crab. The female raises its body with the help of walking legs and abdomen is fully stretched with vigorous jerking of the berry. As a result the compactness of the berry is lost and setae get themselves loosened from the bunch. The stiff hairs along the margin of the terminal segment of the second and third pairs of walking legs are used for the purpose of detaching the hatching eggs from the pleopods. All the eggs are shed in about 1-2 hours time in cases where direct observations were possible. Some of the eggs hatch while they get detached from the endopodites of the abdomen but the majority of them sink to the bottom of the tank where it burst and larvae get released.

In majority of the cases, full hatching was recorded. Whenever partial hatching was occurred, the remaining eggs were either aborted in the same day or larvae released during next day. These larvae were weak, could not develop into subsequent zoeal stages, unlike the first released set of zoeae. The newly hatched larvae were only in zoeal stage and pre-zoeal stage was never observed. The newly hatched zoeae were active swimmers and highly photopositive. They found aggregating into groups very often near the surface along the sides of the rearing tank.

Growth parameters

The growth in length of laboratory grown male and female *P. pelagicus* was analysed. Linear growth gave high correlation value; however the fitted growth was linear only during its juvenile phase. Growth followed the asymptotic curve as given in the Von Bertalanffy Growth Formula (VBGF) (Fig.4.10 and 4.11). Hence the data was analysed for VBGF using three different methods viz. Gulland and Holt, Munro's and Fabens. The $L\infty$ values ranged between 204.1 and 219.8 mm in males and 188.6 and 211.8 mm in females. The growth coefficient (K) varied between 1.8 - 1.9 and 1.62 - 1.7 in males and females respectively. The details are given in the following table and figures 4.12 to 4.15.

Observed (Lab) and fitted growth (VBGF) in male
Portunus pelagicus

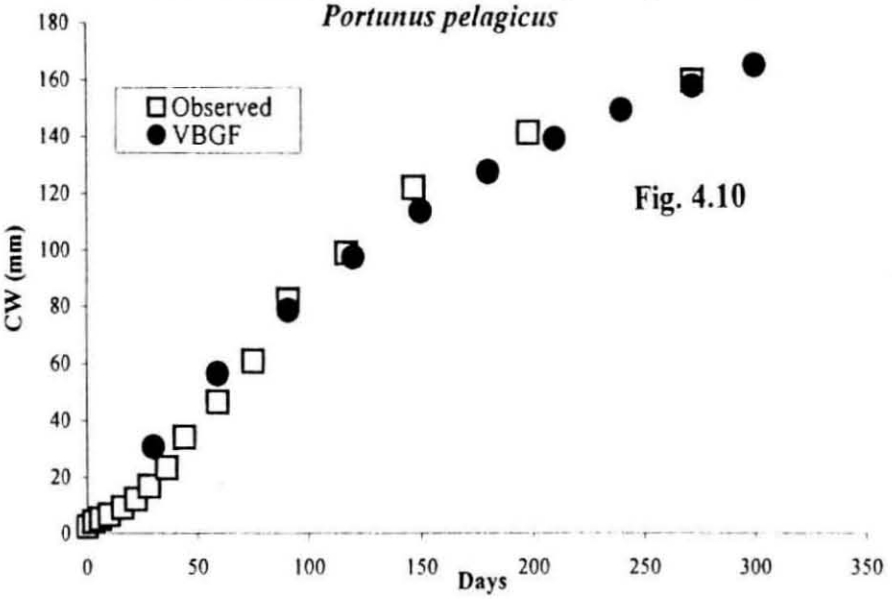


Fig. 4.10

Observed (Lab) and fitted growth (VBGF) in female
Portunus pelagicus

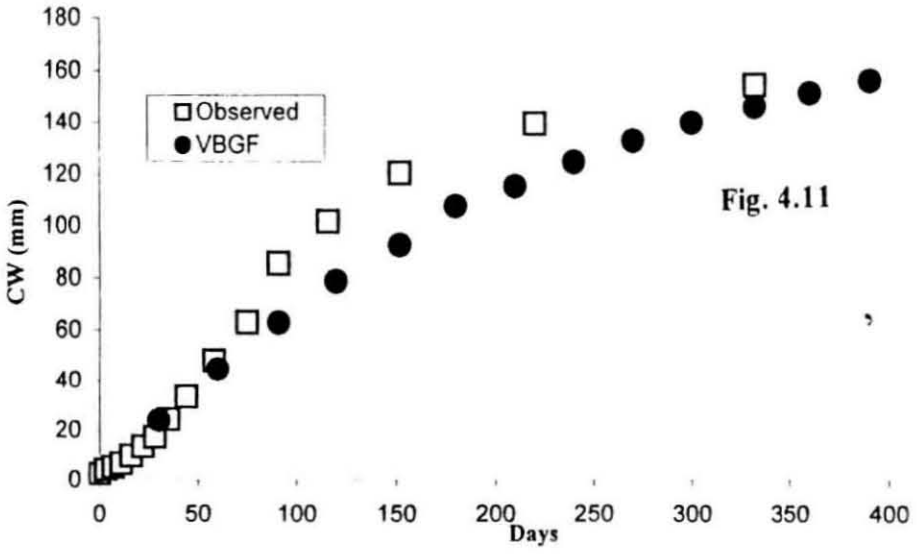


Fig. 4.11

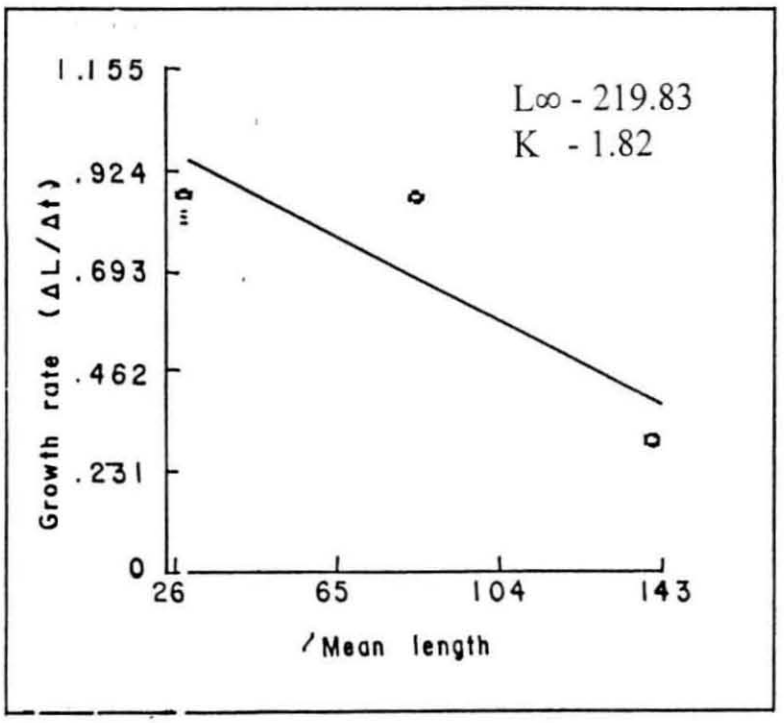


Fig. 4.12. VBGF derived from Gulland and Holt method in lab reared *Portunus pelagicus* Males.

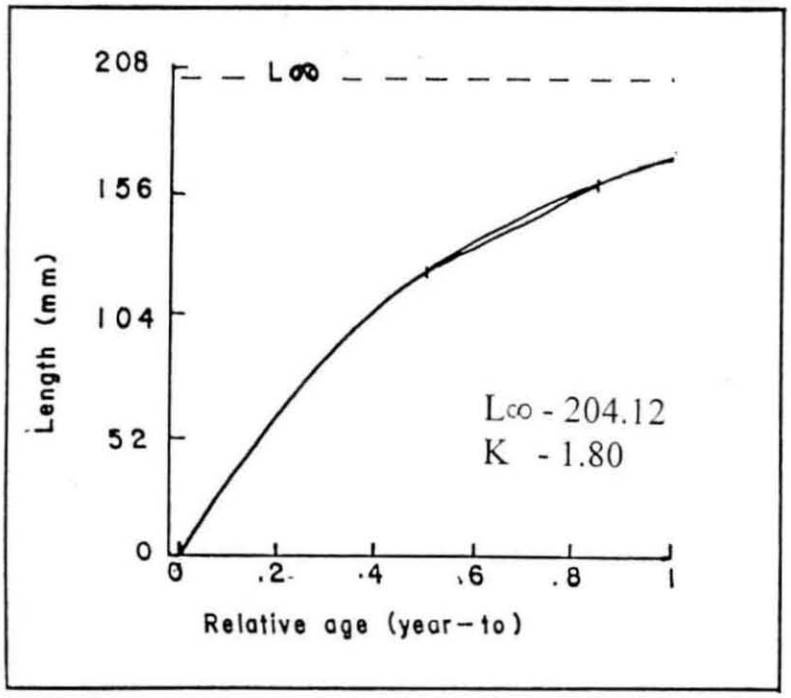


Fig. 4.13. VBGF derived from Fabens method in lab reared *Portunus pelagicus* Males.

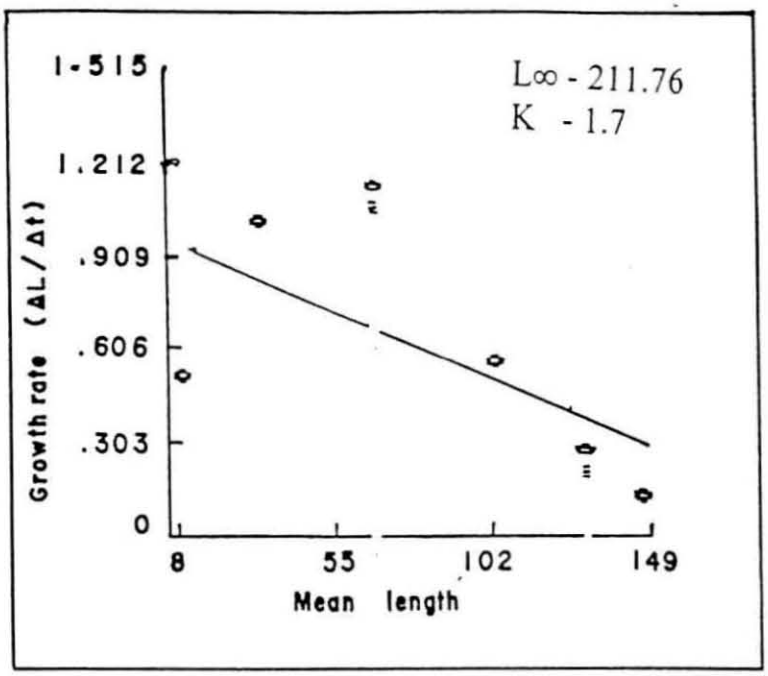


Fig. 4.14. VBGF derived from Gulland and Holt method in lab reared *Portunus pelagicus* Females.

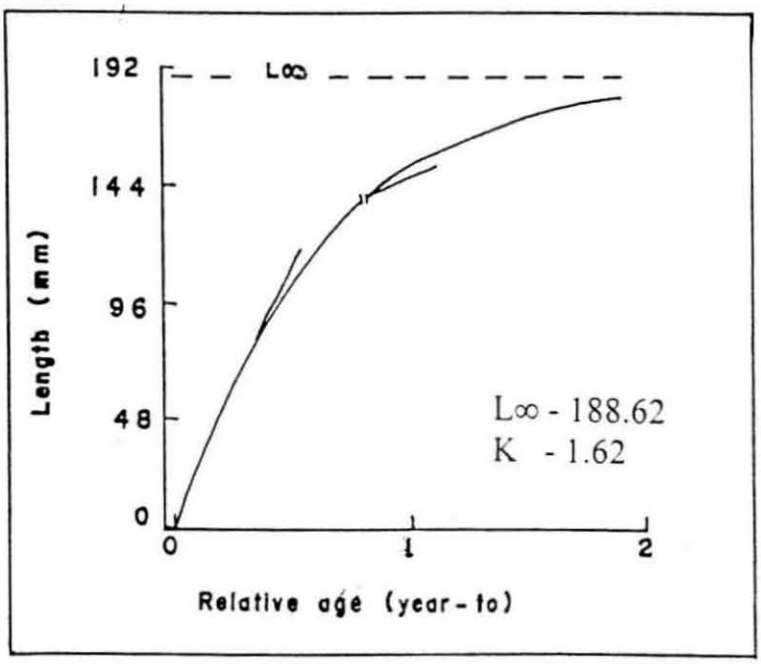


Fig. 4.15. VBGF derived from Fabens method in lab reared *Portunus pelagicus* Females.

Table.4.6. MONTHLY GROWTH OF LABORATORY GROWN MALES OF *PORTUNUS PELAGICUS* (BASED ON THE VBGF)

	$L_\infty \longrightarrow$	219.8	204.1	208.0
AGE	K $\longrightarrow$	1.82	1.80	1.9
MONTH	YEAR			
1	0	30.90	28.40	30.50
2	0	57.50	52.90	56.50
3	0	80.40	74.00	78.60
4	0	100.00	92.10	97.60
5	0	116.90	107.70	113.80
6	0	131.30	121.10	127.60
7	0	143.80	132.70	139.30
8	0	154.50	142.60	149.40
9	0	163.70	151.20	158.00
10	0	171.60	158.60	165.30
11	0	178.40	164.90	171.60
12	1	184.20	170.40	176.90
13	1	189.20	175.10	181.40
14	1	193.50	179.10	185.30
15	1	197.20	182.60	188.70
16	1	200.40	185.60	191.50
17	1	203.10	188.20	193.90
18	1	205.50	190.40	196.00
19	1	207.50	192.30	197.70
20	1	209.20	194.00	199.20
21	1	210.70	195.40	200.50
22	1	212.00	196.60	201.60
23	1	213.10	197.60	202.50
24	2	214.10	198.50	203.30
25	2	214.90	199.30	204.00
26	2	215.60	200.00	204.60
27	2	216.20	200.60	205.10
28	2	216.70	201.10	205.50
29	2	217.10	201.50	205.90
30	2	217.50	201.90	206.20
31	2	217.80	202.20	206.50
32	2	218.10	202.40	206.70
33	2	218.40	202.70	206.90
34	2	218.60	202.90	207.00
35	2	218.70	203.00	207.20
36	3	218.90	203.20	207.30

Table. 4.7. MONTHLY GROWTH OF LABORATORY GROWN FEMALES OF *PORTUNUS PELAGICUS* (BASED ON THE VBGF)

	$L_\infty \longrightarrow$	211.8	188.6	211.0
AGE	K $\longrightarrow$	1.70	1.62	1.64
MONTH	YEAR			
1	0	28.00	23.80	27.0
2	0	52.20	44.60	50.5
3	0	73.30	62.80	71.0
4	0	91.60	78.70	88.9
5	0	107.50	92.60	104.5
6	0	121.30	104.70	118.1
7	0	133.20	115.30	129.9
8	0	143.60	124.60	140.3
9	0	152.60	132.70	149.3
10	0	160.40	139.70	157.2
11	0	167.20	145.90	164.1
12	1	173.10	151.30	170.1
13	1	178.20	156.00	175.3
14	1	182.60	160.10	179.9
15	1	186.50	163.70	183.8
16	1	189.80	166.90	187.3
17	1	192.70	169.60	190.3
18	1	195.20	172.00	193.0
19	1	197.40	174.10	195.3
20	1	199.30	175.90	197.3
21	1	201.00	177.50	199.0
22	1	202.40	178.90	200.6
23	1	203.60	180.20	201.9
24	2	204.70	181.20	203.1
25	2	205.60	182.20	204.1
26	2	206.40	183.00	205.0
27	2	207.10	183.70	205.7
28	2	207.80	184.30	206.4
29	2	208.30	184.90	207.0
30	2	208.70	185.30	207.5
31	2	209.10	185.70	207.9
32	2	209.50	186.10	208.3
33	2	209.80	186.40	208.7
34	2	210.00	186.70	209.0
35	2	210.30	186.90	209.2
36	3	210.50	187.20	209.5

Method	L∞ (mm)	K	Growth equation
Male			
Gulland and Holt	219.8	1.82	$L_{(t)} = 219.8 \{1-\exp^{-1.82 (t-t_0)}\}$
Munro's	208.0	1.90	$L_{(t)} = 208.0 \{1-\exp^{-1.90 (t-t_0)}\}$
Fabens	204.1	1.80	$L_{(t)} = 204.1 \{1-\exp^{-1.80 (t-t_0)}\}$
Female			
Gulland and Holt	211.8	1.70	$L_{(t)} = 211.8 \{1-\exp^{-1.70 (t-t_0)}\}$
Munro's	211.0	1.64	$L_{(t)} = 211.0 \{1-\exp^{-1.64 (t-t_0)}\}$
Fabens	188.6	1.62	$L_{(t)} = 188.0 \{1-\exp^{-1.62 (t-t_0)}\}$

Based on the L∞ and K values monthly growth of *P. pelagicus* male and female was computed using the inverse VBGF and are presented in the table 4.6 and 4.7. The monthly growth estimates of male *P. pelagicus* following the Munro's method, when compared to actual observed values, gave very close values, while in females the observed mean growth was close to that observed in the Faben's method. Accordingly males and females attained a length of 176.9, 203.3 and 207.3 mm and 151.3, 181.2 and 187.2 mm at the end of 1st , 2nd and 3rd year respectively.

DISCUSSION

In *Portunus pelagicus* there are four zoeal stages and one megalopa stage. The megalopa metamorphosed directly to the first crab instar. In the present study the total duration of the larval development varied between 14-17 days. The first and second zoeal stages spanned for 3-4 days each, third and fourth stages for 2-3 days each and megalopa 3-4 days. The first crab instar emerged between 15th and 18th day. According to reports of several workers on most of the portunine crabs, the number of zoeal stages varied between 4-7. Many workers have reported the existence of five zoeal stages in *Scylla serrata* and each zoeal stage spanned for 3-5 days (Ong, 1964, Brick, 1974; Haesman and Fielder 1983, Marichamy and Rajapackiam, 1984,1992; Marichamy 1996; Anil, 1997: Kathirvel *et al.*,1997).. In a closely related species, American blue crab *Callinectes sapidus,* Costlow and

Bookhout (1959) observed 7 zoeal stages. Complete larval development of *Cancer magister, Cancer irroratus* and *Cancer gracilis* has been reported by Poole (1966), Sastry (1970), Charmantier and Charmantier (1991) and Ally (1975) respectively. All the three species have 5 zoeal stages. In *Thalamita crenata*, 5 zoeal stages are reported (Krishnan and Kannupandi, 1990 and Godfred *et al.*, 1995). However, Greenwood and Fielder (1979) observed that the megalopa stage in *Portunus rubromarginatus* was reached in a minimum of 10 days after hatching and found that this species is having only 3 zoeal stages which is quite unusual amongst portuninae species.

In India, there are no previous descriptions of the complete series of larval stages of *P. pelagicus.* Prasad and Tampi (1953) described the first zoea of *P. pelagicus* (as *Neptunus pelagicus*) from laboratory-hatched larvae but the descriptions of the later zoeal stages were from the plankton collection and not from laoratory hatching. Chhapgar (1956) described the megalopa of *Portunus pelagicus* (as *Neptunus)* from the Bombay coast. According to Bookhout and Costlow (1974) "the larvae within the subfamily Portuninae are so similar, that it is very difficult to tell species apart from other than by examination of minute characteristics of those larvae which have been cultured from the egg". Raman *et al* (1987) studied the larval development of *P. pelagicus* under laboratory conditions and found 3 zoeal and one megalopal stage. In the present study it is distinctly clear that there exsists 4 zoeal stages and disagree with the above conclusion. They have not studied the larval characteristics of each zoea and perhaps taken Z-II and Z-III as one stage. Delsman and De Man (1925) described the freshly hatched early zoea of larvae of *Portunus pelagicus* (as *Neptunus).* Aikawa (1929) described the first zoea of closely related species *P. trituberculatus.* The number of zoeal stages observed in the present study is in conformity with the works of Yatsuzuka (1962), Kurata and Midorikawa (1975) and Shinkarenko (1979).

Prasad and Tampi (1953) distinguished a pre-zoeal stage in the larval development of *P. pelagicus.* However, in the present study the newly hatched larvae were in first zoeal stage only. No pre-zoeal stage was observed in all the hatchings. They also point out that these larvae assume all the characters of first zoea in the

course of about two hours and they could not rear the larvae more than twenty hours in the laboratory. Later stages reported are based on the zoeal collections from the wild, hence except for their description of the first zoea, other zoeal stages are unreliable.

Other workers also have reported 'Pre-zoeal' stage while rearing the crabs in the laboratory; Lebour (1928) in *Portunus puber;* Davis (1965) in *Callinectes sapidus,* Ong (1964) in *Scylla serrata,* Ally (1975) in *Cancer gracilis* and Andryszak and Gore (1981) in *Micropanope sculptipes.* Sandoz and Hopkins (1944) and Sandoz and Rogers (1944) opined that the larvae came out as pre-zoeal, only under abnormal conditions, such as low salinities or bacterial and fungal infection.

Lebour (1928), while discussing the primitive nature of the Brachyrhyncha larvae, considers *Portunus* as most primitive because of the many zoeal stages and the structure of the spine on the telson. Costlow and Bookhout (1959) and Costlow (1965) also suggest that the morphological variability found in the zoeal development of portunids is associated with the primitive nature of the family. According to Krishnan and Kannupandi (1990) only within Portunidae do any species occur with more than five zoeal stages and for this reason it is considered to be the most primitive family within the Brachyura. The morphological variations encountered in the developemental stages of Portunids may be intrinsic.

Larval morphology in the present work is comparable with that of Shinkarenko (1979) from Australian waters, the only available complete larval study on *P. pelagicus.* As in the present work, he also reported four zoeal stages; however variations are observable in the pattern of setation in different appendages. In the present study, the number of aesthetes and setae of antennule in the four zoeal stages are 2+0/2, 5+0/1, 4+2/1 and 4+5/1 respectively in which aesthetes are arranged in two groups, terminal and sub-terminal. Shinkarenko (1979) reported the antennular setae as 2+0/11, 7+0/2, 5+1/2 and 5+4/2 respectively. The descriptions for antenna, maxillule and maxilla are found similar in both works. The pattern of setation in first and second maxillipeds are found to be different in present work. The number of setae in exopod of these appendages is in the order of 4,4,5-6,12 and 4,8,10,12 respectively. But, in the other work it was reported that the number of setae in the

exopod of first and second maxillipeds is same i.e. 4,8,10,14. Another important difference is in the appearance of pleopod buds; in the present study the pleopod buds are visible only from the 3rd zoeal stage, whereas he has reported that pleopod buds are visible from the 2nd zoeal stage. There is also disparity in the number of small setae present in the centre of the median curve of the telson, in the 3rd and 4th zoeal stages. In the present work the number is 2 and 3 respectively whereas, in his report it is 3 and 4. Megalopal description is similar in both works except for the segmentation of endopod of third maxilliped and pereiopods. In the present observations endopods of these appendages are 5 segmented whereas he has described these are 6 segment appendages.

Stephensen (1972) has suggested that *P. pelagicus* may be divided into Chines and subspecies. The differences between the setal numbers of various appendages given by Shinkarenko and the present study may be because of the larvae reared in each study belonged to different subspecies of *P. pelagicus* from two different distant geographical locations.

The zoeal appendages show wide variety; and the density and size of setae changes in each zoeal phase. The types of setae and their location on these appendages are similar to those of *P. spinicarpus* (Bookhout and Costlow, 1974) and can be related to the similar carnivorous diet shown by these two species. The abdomen in *P. pelagicus* zoea is very important in the capture of prey and also holding the prey against the mouthparts. The serrated setae in the curve of the telson assist in the abrasion of the prey. Ong (1964) also found that the curvature of the abdomen aided in catching prey in suspension by the zoea of *S. serrata* where the abdomen is also used to press the prey to the mouthparts. The zoea of *P. spinicarpus* also possesses serrated setae on the median curve of the telson. The function of the abdomen in prey capture, holding the prey against the mouthparts and prey abrasion apply in general the same as in other carnivorus zoea.

In the megalopal stage, for capturing prey chelipeds are used rather than the abdomen as in zoeal stage. The abdomen can no longer assist in prey-capture and holding prey against the mouthparts as it is reduced in size and more rigid, bearing the pleopods. The telson is rounded and has lost the serrated setae used for the prey

abrasion in the zoea. The function of holding the prey against the mouthparts in the megalopa is now carried out by the second and third maxillipeds. The endopods of second and third maxillipeds are large and well armed with several serrated setae that help the breaking down of the prey. The terminal segments of the second and third pereiopods of the megalopa bear serrated setae on its inner margin. These pereiopods also assist in holding the prey and prey-abrasion. The coxal and basal endites of first maxillipeds are well developed with many plumose setae for collecting and transferring the broken up pieces of food towards the mouth. The mandibular palp also aids in transferring soft pieces of food into the mouth.

Ong (1964) described the larval stages of *Scylla serrata*, which occurs in much of the geographical range of *P. pelagicus*, and zoeae of these two species are similar in most respects and to distinguish between them is difficult. Shinkarenko (1979) reported that the first zoeae of the two species can be recognised in southeastern Queensland by the number of aesthetes of the antennule; *P. pelagicus* has two and *S. serrata* has three. This is in conformity with the present observations. From the present study it is understood that *Scylla* zoeae can be distinguished from *P. pelagicus,* by the examination of exopods of the maxillipeds and scaphognathite, the number of setae in these appendages vary considerably. Moreover, these are the easiest appendages to observe or remove and therefore have the most practical value for identifying the stage and species of zoea.

In the present study larval mortality was spread throughout the four zoeal and megalopa stages and was not confined to any one particular stage of development. However, highest mortality occurred during the transition from first zoea to second; fourth to megalopa and megalopa to crab stage. This may be due to the inability of the larvae to break completely away from their casts. Many workers have reported that the mortality was high during the first zoeal moult to second zoea in *Scylla serrata* (Ong, 1964; Haesman and Fielder, 1983; Anil, 1997).

Costlow *et al.* (1962) also observed high larval mortality in the first zoeal stage in *Panopeus herbstii.* Anil (1997) reported 40% mortality in the first zoeal stage in *Scylla oceanica.* Costlow and Bookhout (1959) in *Callinectes sapidus* and Raman *et al.* (1987) in *P. pelagicus* have reported high larval mortalities in the first two zoeal

stages. In *Cyclograpsus cinereus*, Costlow and Fagetti (1967) found more mortality in later zoeal stages.

Quantifying patterns of crustacean growth is difficult. There has been a long history of studies, yet there are no generally accepted models describing crustacean growth which are comparable to models applied widely on fish growth. Among the reasons for this are the complications of growth by moulting and the variety of life history strategies expressed by crustaceans. The best confirmation of the growth pattern in a species is by observation of moulting. Crustacean growth is dependent upon the duration of the intermoult (moult interval) and size increase at each moult (moult increment), (Hartnoll, 1982).

The results of the laboratory studies show that growth is fast and a carapace width of 100 mm was reached within an average period of four months. In males, maturity was attained earlier than females *i.e* in three months time and in females about within five months. From the Indian waters only two reports are available on the laboratory growth of *P. pelagicus*. In the first one Prasad and Tampi (1953) reported that wild collected megalopa of *P. pelagicus* from Palk Bay, Mandapam, took one month to attain a size of 8.5 mm carapace width. In the present study the maximum days taken by the juvenile crab to reach approximate size (9 mm cw) was 24 days including the megalopal phase and minimum was 16 days. Compared to the present study the intermoult duration is lengthy; however, it is difficult to reach such strong conclusion as their report is based on a single experiment. The second report is also from Mandapam area (Ameer Hamsa, 1982) and he found that 11-25 mm CW crabs kept in tanks attained a size of 140-150 mm in 12 moults after a period of 14 months. In comparison with the present data, in experiment, the total period taken by the animals was lengthy and he has given only a range for the initial as well as for the final sizes. For instance, initial size of 11-25 mm CW crabs definitely do not belong to a single size group, it's quite obvious from the present study, these crabs comprised of three size groups with minor variations in both sexes. In males the average carapace width was 12.13, 16.63 and 23.17 mm and in females these values were 13.4, 17.2 and 24.27 mm. He has also mentioned that for attaining a size of 140-150 mm the animals have undergone a total of 12 moults. That also found to be

indifferent from the present observation, here both male and female attained 141.39 mm and 139.29 mm (CW) after 9 moults from an initial size of 12.13 mm and 13.4 mm (CW) respectively. Moreover the author has not given the growth of males and females separately. It is definite that in bigger crabs there will be overlapping of size groups, so a given range of CW may contain more than one size group. However, in small crabs though differential growth exist, the range will be small and hence 11-25 mm carapace width range given by Ameer Hamsa (1982) did not belong to the same size group and the total number of moults certainly be less than 12 moults. Similarly Menon (1952) gave the moulting and growth of closely related species *Neptunus sanguinolentus*. His conclusions were based on the growth of two post larval instars only and first one lived for a month and reached a size of 31 mm; the second one (8 mm CW), after 50 days reached 41 mm CW. In the first case (he has not mentioned the size it was assumed that the specimen was in its first instar stage), the growth was faster compared to the second one and almost similar to *P. pelagicus* growth. He also inferred that there were 11 moults during growth between 13 and 60 mm, based on one-year fishery data, and suggested confirmation of the moult number by rearing. Moult numbers were found to be more, during the same spell of growth *P. pelagicus* took only 5 moultings, even if growth is less in *P. sanguinolentus* than the *P. pelagicus*, there is no chance of eleven number of moults and strongly disagree with his findings. As he suggested only by rearing the moult numbers can be confirmed.

The duration of the successive instars increased after initial transformation from megalopa to first crab stage. Marked variations were observed in the carapace colour pattern of the early stages of crabs in all the trials. Some individuals appear almost white without any markings. These variations disappeared as the crabs reached the 5^{th} or 6^{th} instar. Similar observations were recorded in another portunid crab *Cancer anthonyi* (Anderson and Ford, 1976).

The average moult increments of males and females at a carapace width of 100 mm or in other words till the attainment of sexual maturity were similar, at larger sizes the moult increment of females was considerably less. Mackay and Weymouth (1935), Butler (1961) and Bennett (1974) have come to the same conclusion in their studies on another portunid crab of *Cancer* spp. In females the annual growth is less

than that of males due to their smaller moult increments and lower moult frequency. Reduction in moult increments, may be due to the competition for nutritive resources between egg production and body growth. The portunid crabs are capable of multiple spawnings from a single impregnation at the previous moult. This is also another reason for the lengthy moult cycle in female crabs. Williamson (1900) suggested that the presence of sperm in the spermatheca of a female crab inhibits moulting and that the batch of sperm will fertilise two or more annual spawnings. Watson (1970) and Hartnoll (1974) opined that majority of the female portunid crabs showed negative allometry as the frequency of moulting decreases after puberty weight of male crabs also considerably greater than the female crabs. This increase in total weight in males can be observed after the attainment of maturity. In the present study 14, 15 and 16 instars of male attained a total average weight of 123.14, 188.92 and 275.00 g whereas female recorded 106.50, 150.50 and 210.33 g respectively. Accentuation of the larger increments in weight at moulting of male crabs may be due to the allometric growth of their chelae. Moult frequency in male crabs seems to be more closely related to total live weight than to carapace width. Female moult frequency was equally related to carapace width and total live weight. Other workers also reported that the difference between the sexes is probably due to the greater size of the male chelae which results in male crabs being heavier than females of the same carapace width (Hancock and Edwards, 1967; Bennett, 1974). It was evident from the present study that female *P. pelagicus* take more period than males, eventhough the growth is slightly faster in females till they attain 100 mm carapace width. To reach 16th instar stage from the first instar, males took only an average of 272 days but females attained the same stage after 332 days, eventhough the total carapace width and total weight was less. Mauchline (1976) concluded that the length of the intermoult period increased directly as the cube of the body length or logarithmatically as the body length or in relation to the successive moultings. Present findings are also in conformity with that of Carroll (1982), reported that unsexed juveniles have a constant ratio between chela height and carapace width upto approximately 65 mm CW, beyond this size, discontinuous relative growth occur as chela height to carapace width ratios of sexually mature males and females diverge

from the juvenile proportions. In deep sea red crabs *Geryon maritae* (Melville-Smith; 1989), it was observed that females grow slightly faster than males upto the point they attain maturity, but thereafter their growth was extremely slow. Mc Caughran and Powell (1977) reached a similar conclusion, in the growth of *Paralithodes camtschatica*. In *Cancer pagurus*, the moult frequency of females fell at a faster rate than the males however the average weight increment of 250g sizes females was only 85% whereas, male crabs showed an average increase of 121% at moulting (Bennett, 1974).

Hiatt (1948) reported that in *Pachygrapsus crassipes* the percent increment change was greater in smaller crabs. In the present observations too, both in male and female crabs the percentage of increment in total weight, carpace width and length were more in juvenile crabs till their maturiy. Marshall (1945) reported that negative growth and moulting without growth occurred in *Panulirus argus* and Travis (1954) indicated that only occasionally she recorded moulting without growth. But in *P. pelagicus* it was never observed a moult without growth or negative growth. It was pointed out by Sather (1966) that two parameters are determental in relative growth studies in crustaceans; first one being the weight gain during successive moultings and increment changes in length and width between two successive moults. The former reflects changes in water content prior to ecdysis followed by a concomitant increase in tissue mass. The author did not observe any sexual difference in the increment of length and width in the crab *Podophthalmus vigil* and the percent increase in carapace width was slightly greater in smaller crabs. However, in his studies he never observed the process of 'negative growth'.

Growth in crustacean is a discontinuous process, lost of appendages can be replaced only by moulting. Smith (1990) indicated that the cost of autotomy for crustaceans, therefore, could be high since these animals must survive one or more moult cycles before an appendage can be regenerated completely. He has conducted studies to examine long term effects of autotomy on the growth of portunid crab, *Callinectes sapidus*, found that loss of a single cheliped, could regenerate almost 90% of the normal limb length in the first autotomy moult and nearly 100% of the length by the second moult. In the present observations too, *P. pelagicus* was able to

regenerate the lost single chelae or other limbs to 90% normal size in the next moult and it did not affect the moult increment and interval moult. However in multiple limb loss both moult interval and moult increment had an adverse effect. Smith (1990) also reported that, multiple limb loss, reduced the moult increment and percent weight increase in the first post-autotomy moult did not affect the duration of the moult. Effects of limb loss appear to be additive, such that, the moult increment decreases proportionally as increasing numbers of limbs are lost (Bennett, 1973 and Kuris and Mager,1975). Studies on the same species by Ary *et al.* (1987) showed that limb removal in early stages of anecdysis did not significantly affect the duration of the intermoult compared to the intact controls. Bennett (1974) estimated that autotomy was responsible for only a 3% reduction in growth in *Cancer pagurus*. Edwards (1972) reported that complete regeneration of appendage length in king crabs, *Paralithodes camtschatica* could take 4-7 years.

The two most important environmental factors, which affect the moulting and growth in crustaceans, are temperature and quality and quantity of food. Compared to these parameters light and salinity are having little effects on both moult and intermoult period. India, being a tropical country, *P. pelagicus* growth is not affected by temperature, moreover, at Mandapam temperature is always on the higher side throughout the year, different from temperate countries, where temperature plays a significant role. Temperature is a variable known to affect the growth of many crab species (Hartnoll, 1982) and is the abiotic variable with the most obvious change along the geographic range of the Dungeness crab. Kondzela and Shirely (1993) worked out the increment in carapace width and wet weight juvenile Dungeness crabs. The intermoult period was the growth component most affected by temperature, the warmer the water temperature upto 15°C, the shorter the intermoult period. Whereas its effect on the size of moult increments was minimal, at 5, 10 and 15°C there were no significant differences in size of moult increments. Hartnoll (1982) and Mauchline (1976) opined that its effect on moult increment may vary, but usually intermoult period become shortened. In *Callinectus sapidus* average growth rate increased with temperature from 13°C to 34°C (Leffler, 1972). He also informed that in *C. sapidus* farms, using heated effluent water in the winter and cooler offshore

water during summer, could grow blue crabs from first instar to market size in 7 to 8 months rather than normal 10-11 months. Travis (1954) found correlation of moult frequency with temperature in lobster, *Panulirus argus*. In *Pachygrapsus crassipes*, a marked correlation between moulting frequency and water temperature was observed by Hiatt (1948). The second factor - food - might have not affected *P. pelagicus* growth in the present study, as the animals were well fed throughout the period. Salinity variations were only in a narrow range so it is assumed that it has not a major factor determining its growth. In his review, Hartnoll (1982) concluded that in many growth studies in several species of crustaceans, there were no significant changes in the intermoult period with reference to salinity.

In all brachyurans investigated so far, mating males were invariably hard. The extensive survey by Hartnoll (1969) showed that, in Cancridae and Portunidae, mating females are normally soft and in some groups like Majidae, in which mating occurs in both soft-shelled and hard-shelled females. Soft female mating has based on the complexity of female genital ducts, been suggested to be more primitive mating behaviour (Hartnoll;1968,1969). Females about to moult release a pheromone which attracts the male (Ryan, 1967c) and this male then protects the female during the critical time surrounding moult and mates with her shortly after she has moulted. In *P. pelagicus* mating always seen associated with females moulting with a hard male. However, Broekhuysen (1936) has been observed in copulation in *P. pelagicus* and *Uca pugilator* when the carapace of the female was hard. Another report of copulation between hard males and hard females given by Boolootian *et al.* (1959) in *Pugettia producta*.

Cheung (1966) described the act of copulation in *Carcinus maenas*, reported that a single soft female copulated with two males one by one. In the present observations, many occasions it was seen that at the moulting of female more than one male accompany her and then and there fought between to catch the female. However it is not very sure whether actual mating took place with two males. Multiple matings and egg fertilization with stored sperm were also known to occur in a variety of spider crabs (Hartnoll, 1963; Watson, 1970, 1972; Hinsch, 1972; Adams and Paul, 1983; Paul, 1984). In golden crab, *Geryon fenneri*, females appear to be

capable of mating while in the hardened condition (Hinsch, 1988).

In portunid crabs pre-moult carrying embrace was observed, in *P. pelagicus* too, it was very evident in the captive animals. Elner *et al.* (1987) reported that in *Geryon quinquedens* appeared unique in not establishing a pre-moult carrying embrace. Murai *et al.* (1995) while the studying the courtship in *Uca tetragonon* have seen male display by claw-waving to attract females to burrows of males for mating. Such sort of attractive displays were not seen in *P. pelagicus* during the course of the study.

There are cases in which mating does not lead to egg bearing in females. Edwards (1979) reported in *Cancer pagurus* mating can take place without subsequent egg carrying particularly in the small sized crabs. It was noticed that in the present study, two of the females did not spawn after their first maturation moult. However, they have spawned twice after the 2nd maturation moult.

The size of eggs in the berry found increasing as the embryonic development progressed and in *P. pelagicus* the mean size ranged between 336-428 μ . In reports of Prasad and Tampi (1953) the egg size of *P. pelagicus* varied within a narrow range of 360-375 μ from Mandapam and Pillai and Nair (1973b) recorded egg size about 343μ from Cochin area. However, they have not mentioned the stage of berry when egg measurement has taken. In the case of congeneric species *P. sanguinolentus* Naidu (1955) recorded 280-380μ and George (1963) about 290μ, the former has given a wide range similar to the present findings in two closely related species, *Scylla serrata* and *S. tranquebarica* the egg diameter ranged between 280-390μ (Pillai and Nair, 1973b; Marichamy and Rajapackiam, 1992 and Anil, 1997). Radhakrishnan (2000) reported that peak protein content with less fat is observed during the yellow and orange stages of embryonic development, while fat value increases and protein value drops during the advanced stages of development in *P. pelagicus*.

The egg size is dependent on the amount of nutritive substance present in it and has a relation to the duration of the planktotrophic life of the larva, the size being inversely proportional to the duration of the free swimming period (Pillai and Nair, 1973b). Therefore, it can be inferred that the swimming crabs have comparatively

longer periods of free swimming larval period when compared with those of the deep-water crabs and shore crabs. Many authors have reported larger yolky eggs for deep-sea brachyuran crabs (Haefner, 1977; Hines,1988; Padayatti, 1990; Balasubramanian, 1993 and Carsen *et al.*, 1996).

Growth followed Von Bertalanffy growth function in males and females. Male crabs attain a carapace width of 207.3mm at the end of third year (L_∞ 208.0). The maximum size (L_{max}) recorded in the fishery was 195 mm. While females attain a carapace width of 187.2 mm (L_∞ 188.6) by the end of third year. The maximum size recorded in the fishery was 193 mm. So it is possible that crabs may live a few more months and chances are there for one more moulting. Hence it can be deduced that the lifespan of *P. pelagicus* may be around three years.

CHAPTER V

CHAPTER V

HATCHERY TECHNOLOGY

INTRODUCTION

Availability of quality seed in required quantity during a prefixed time is one of the essential requirements for the successful crab culture. Wild seed resources in the long run can meet the species and size specific need very little. Further, harvest from wild will adversely affect the adult population size which is fished and exported now. Compared to shrimp seed collection, collecting crab seed is highly laborious and undependable. Shrimp seed production technology is perfected and is adapted in all shrimp hatcheries in the west and east coasts of India like elsewhere in the globe with suitable species and location specific variations.

During late nineties the cost of pelagic shrimp has increased at least ten fold due to increasing overseas demand. Shrimp culture sector in India is experiencing the impact of devastating viral disease and has driven particularly the corporate bodies out of the scene and many shrimp farmers are looking forward to diversification of culture species in the same farms. At this juncture it is essential to develop a technology to mass produce crab seeds under controlled conditions and upscale it to requirement. In India so far neither a crab hatchery is established nor a near perfect technology is developed for any crab though the culture potential is very high and demand is increasing.

It is ideal to mass produce baby crabs in controlled conditions and develop a technology for easy adoption. So in this direction the present attempt here is to give information about the operation of a small scale blue swimmer crab hatchery which is obtained after repeated larval culture trials with different local cheap live feeds. The existing defunct or under utilized shrimp hatcheries can do crab seed production with a few modifications only in the live feed production section.

Present hatchery design is a built-in facility in which crab larvae are reared upto young ones for farming. A thorough knowledge on the life history of the swimming crab *Portunus pelagicus*; behaviour of the adult and different stages of

larvae; their feed requirements and culture water quality are a few pre-requisites for successful rearing in hatchery phase.

Hatchery – site selection

Site selection for a crab hatchery is an important aspect and the success of the hatchery depends on the site. Round the year availability of good quality seawater of 'near oceanic quality' with a salinity range of 28-34 ppt is essential for continuous seed production. The site should be beyond the realm of salinity dilution by seasonal or perennial rivers and irrigation canals. Seawater temperature should be between 27 and 32 ^{0}C during different seasons; pH between 8 and 8.2 and dissolved oxygen between 4.5 and 6.0 mg/l. The nature of seabottom at water intake point can be rocky or sandy and not muddy. The point must be away from pollution sources like domestic drainage, industrial effluents, shrimp or fish farm effluents and agricultural run off. Locations infested with boring and fouling marine organisms and pathogens must be avoided. Areas of tidal mud flats and mangrove ecosystems should be avoided for hatchery. Site may be over a fresh water aquifer for easy drawal or may be made available easily from municipality. The site should be easily approachable by motorable road and three-phase electricity at a near point is a must. Hatchery must be located at a site from where seed could be transported to farm site within a night's road travel and where demand for seed is more. It is required that the site should not fall within the periphery of frequent natural calamities like cyclone, earth quake and sea erosion.

Building, built –in, summonable facilities

The essential infrastructure facilities for an under-roof hatchery capable of producing 2 million crab seeds per year (at an average minimum survival of 10% from zoea 1 to first crab instar) are described and discussed here. In the hatchery complex, a centrally located building (28.5x15.5 m) is the heart of the hatchery (Fig. 5.1 and plates 18,19). This is built East-West oriented to avoid self-shading particularly for the live feed section. These building houses larval rearing, live feed and broodstock sections, apart from office, laboratory, store and toilet. The concrete floor is gently sloping from the base of the walls at its length towards the centre, where there is a longitudinal drain canal running parallel to walls. This prevents

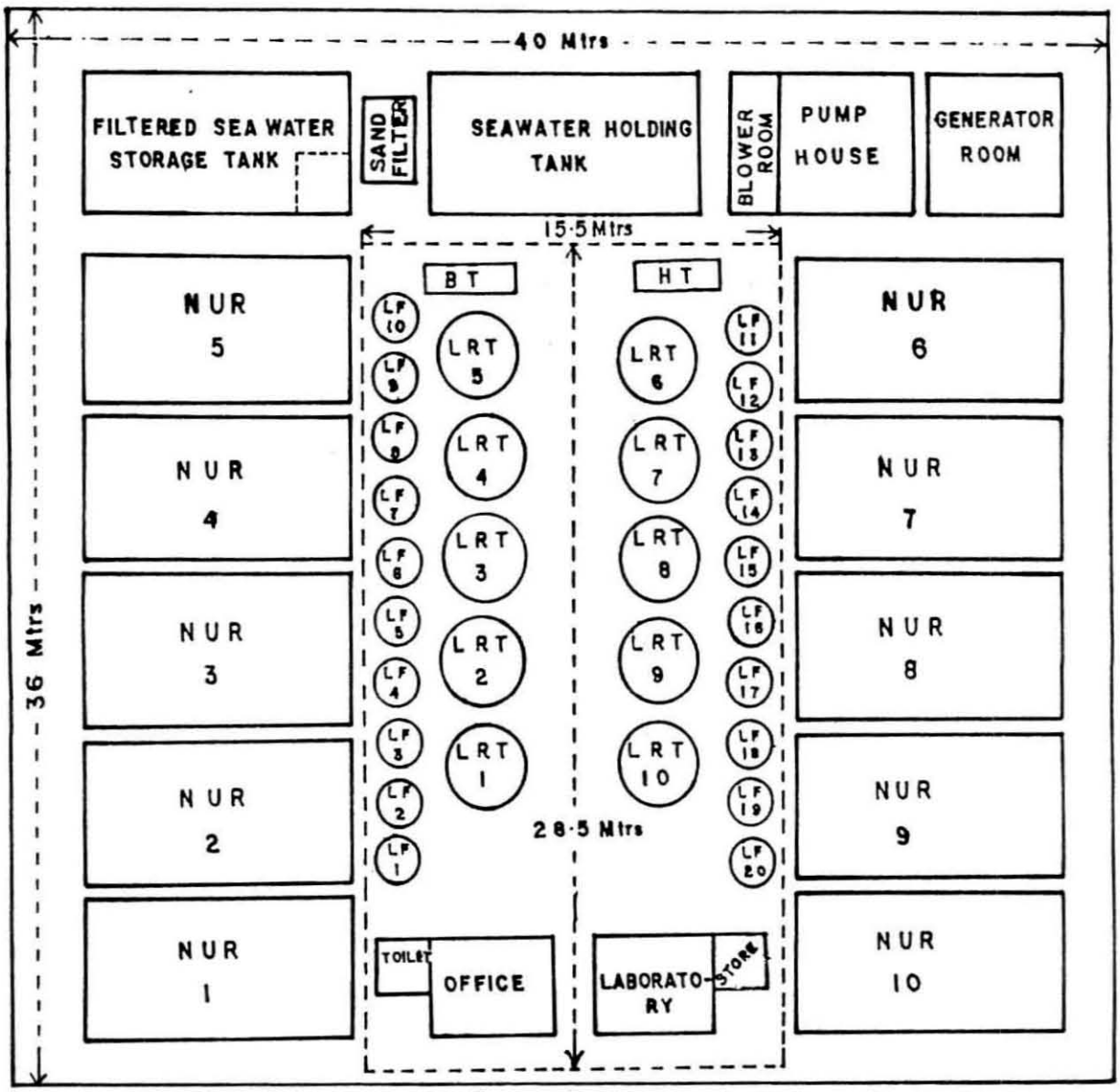
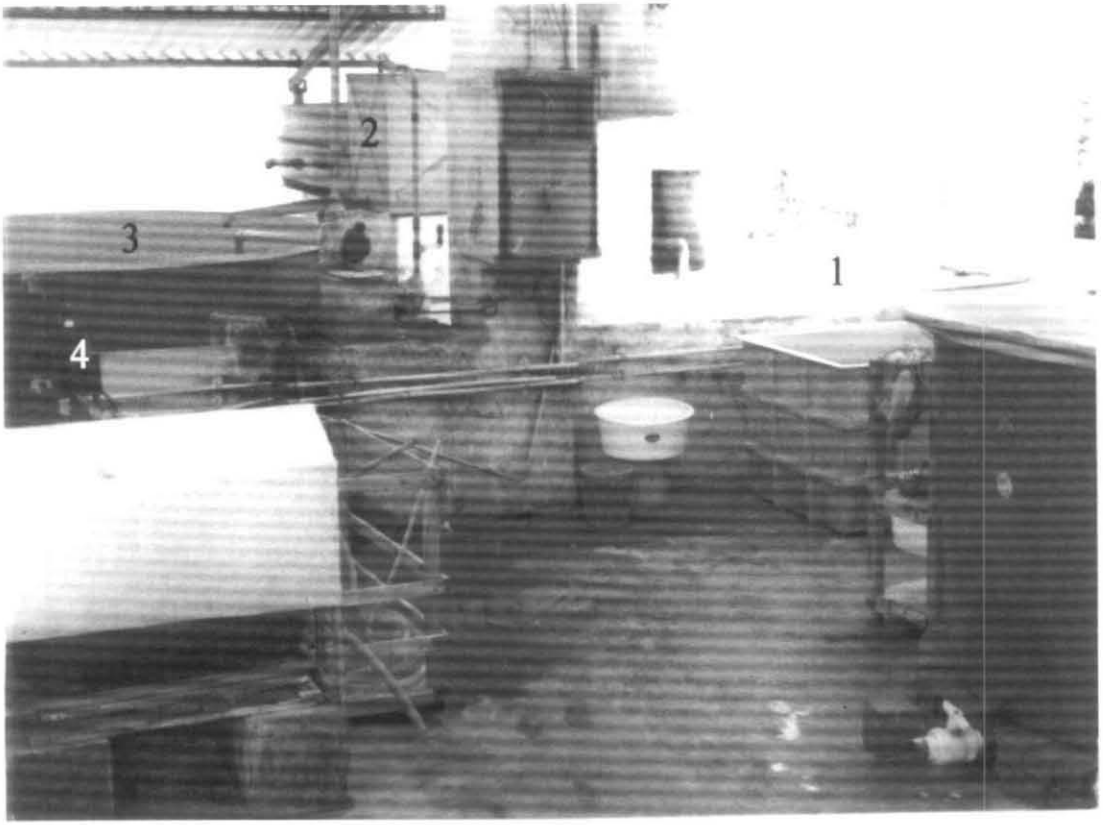


Fig. 5.1. LAYOUT FOR THE SMALL SCALE BLUE SWIMMER CRAB HATCHERY

Scale : 2m

NUR: Nursery tanks; HT- Hatching tanks ; BT- Brood stock holding tanks; LF- Live feed culture tanks; LRT- Larval rearing tanks.

Plate 18



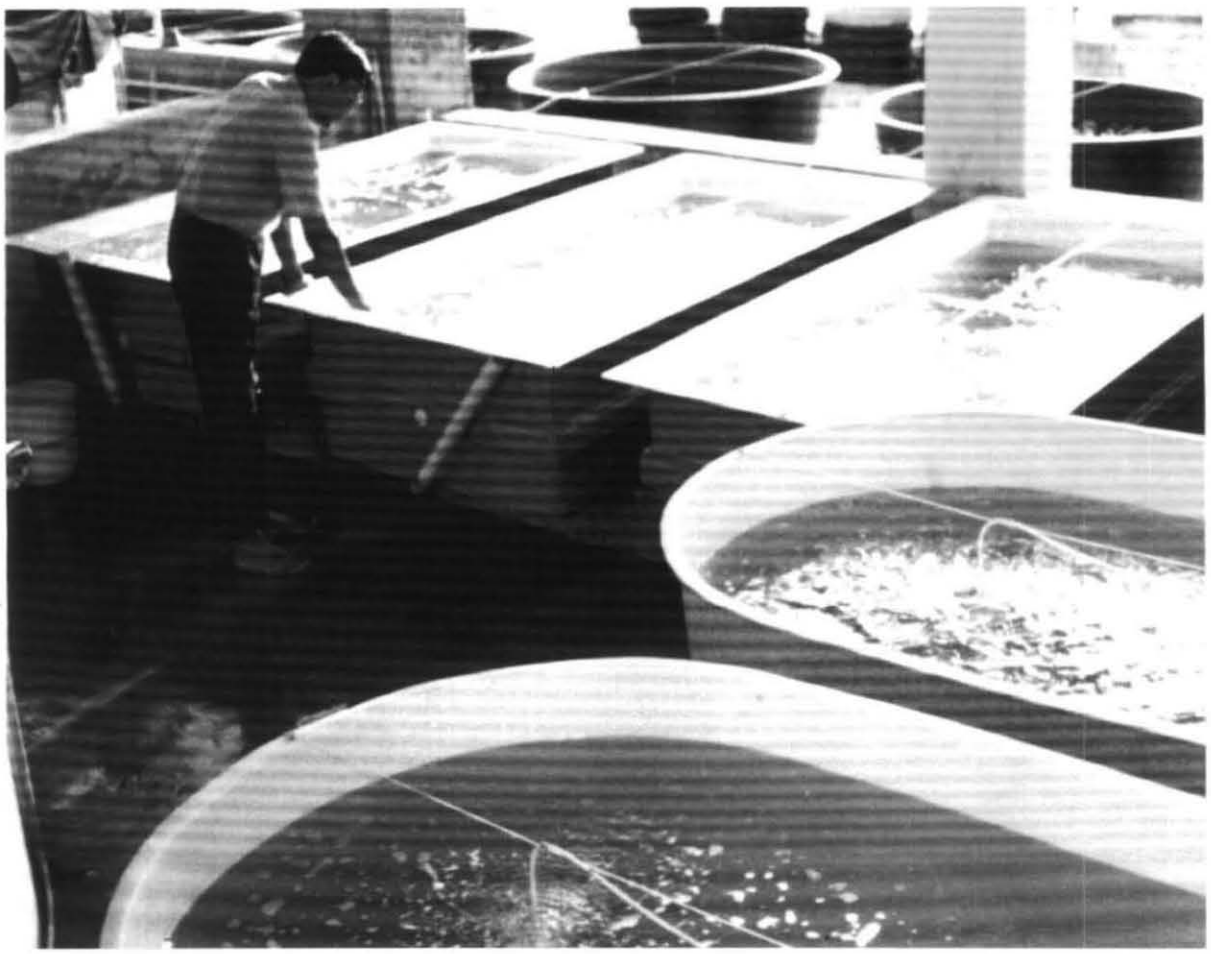
a

b

a. A view of back yard hatchery at CMFRI,Mandapam Camp showing
1) Settling tank 2) Sand filter 3) Sea water holding tank
4) Air compressor

b. Live feed culture tanks (1 t capacity each)

Plate 19



A view of larval rearing tanks inside the hatchery.

permit water stagnation inside the hatchery and keeps the floor dry. The central drain canal is covered with makeshift concrete slabs. The sidewalls are honeycombed to permit cross ventilation to reduce temperature and facilitate quick drying. The roof over the live feed sections on either side is by translucent fibreglass sheets. It permits 60% ambient light to fall over the live feed section only throughout the day as the building is east west oriented. On either sides from the mid roof it is asbestos sheets shading the larval rearing section completely.

Broodstock tank (BT)

This is a 2ton rectangular, wholly drainable, flat-bottom fibre glass tank with black and smooth interior kept at the farthest end of the hatchery right below the asbestos roofing to avoid direct sunlight as far as possible and close to the wall and drain canal. The drainpipe is fitted with a ball valve.

Hatching tank (HT)

This is a 2ton fibreglass tank and other details are as that of broodstock tank but not with black interior. Blue, white or grey interior is preferable. It is kept in an area exactly opposite to brood stock tank area on the other side of the central drain. As the live feed tanks are similar ones it can also be used for hatching when more hatchings are anticipated on a single day.

Larval rearing tanks (LRT)

There are ten equisized 5 ton round fibreglass larval rearing tanks of one metre depth. The interior is smooth and grey. The bottom should not be flat and there should be a gentle slope from all sides towards centre where 63 mm drain opens up which is fitted with a ball valve. A suitable diameter detachable P.V.C standpipe is fitted to the drain opening inside the tank and is always above culture water level. This prevents larvae swim into the drainpipe. While harvesting the central standpipe is removed and seed harvested through the drainpipe. The LRT are kept serially on either side and close to central drain canal (5 tanks in each side). Maximum interspace is given between LRT to avoid splashing of water from one tank over the other to avoid contamination particularly during occurrence of pathogens.

Live feed tanks

Twenty fibreglass tanks of 1ton capacity and 0.75m high smooth and white interior tanks are used for live feed culture. These tanks are totally drainable through the bottom. Drain pipe is fitted with a 2" dia ball valve for total controlled drain. These tanks are kept over a 30 cm raised cement platform along the sidewalls on either side or parallel to the central drain. This area is right below the translucent roofing allowing maximum sunlight for enabling good microalgal production.

At the one end inside the hatchery building there is area for office, laboratory, storeroom and toilet. Laboratory space is also provided for seed acclimation and packing.

Nursery tanks

Outside the above sheltered hatchery building, perpendicular to its length on its left and right flanks very close to the walls leaving 3' space ten '50 ton' rectangular nursery tanks (5 on right and 5 on left) are constructed; the dimension of each tank is 10 x 5 x 1 m and made of brick with smooth cement plastering inside. All the inner corners of the tanks are suitably curved (not finished with 90° sharply) to avoid dead water zones during air bubbling. The tank bottom is gently sloped (1:50) lengthwise permitting total drain through a PVC pipe of 3" diameter with a suitable sized polypropylene ball valve. Arrangements are made to cover only the top of the nurseries in the event of rain or excess heat at a height of 2 m above the tank top. This will permit airflow freely over the tanks. This is not a permanent cover and a detachable type whenever necessary.

Generator, pump house and air blower room

Generator room, pump house and air blower rooms are in this order in between sea and hatchery with common walls in serial. They are under the same roof but in three separate rooms not allowing oil spray and smoke to enter other rooms. This combined facility is away from the main hatchery where larval rearing is done to avoid smoke and noise pollution.

Seawater storage tanks

Raw seawater is pumped and stored in a 10 x 5 x 1 m rectangular open tank. This can be made of concrete or brick with smooth interior and white epoxy coated to

avoid bacterial build up. The inner corners are curved and bottom is sloped to one in such a way to facilitate total drain through a 3" dia. PVC exit controlled by ball valve during cleaning and disinfecting.

Quite adjacent but not with a common wall is an equisized and rectangular shaped tank for seawater holding. In between these two tanks a gravity sand filter is established.

A prefabricated round, high-density polyethylene black tank is kept over a one metre high platform constructed with a single pillar and two beams in one inner corner of the sea water storage tank. Water from this tank is drawn for certain small requirements by gravity to overcome short duration power cuts and under utilizing high voltage motors.

A 2000 litre HDPE tank is also kept over the pump house to store fresh water for human consumption.

Electricity from general grid and installed generator

Three-phase electricity is used for seawater drawal from sea, shifting settled-water to storage tank, distribution to culture tanks once in a day, general lighting. thermal heating of culture water during winter and running the air blower 24 hours non-stop. For these, particularly for air blower uninterrupted power supply is extremely essential. In many places as this cannot be assured it is a must to go in for a suitable capacity air-cooled diesel generator. For present crab hatchery a 15 KVA generator is established to take care of even prolonged power failure in a day. This is kept in a separate room and its smoke is exhausted through a tall smoke pipe as tall as the hatchery so that the smoke does not pollute the culture water. All the necessary powerlines are drawn to points through well-insulated cables to avoid seawater moisture contact. Plug and switch points are placed 4 feet above the hatchery floor.

Aeration

As the organisms, either crab larvae or live feed, are cultured in unusual concentrations, non-stop supplementary oxygen supply is essential. Rigorous air bubbling through seawater in the storage tank for dechlorination is necessary before the use. For all these oil free air is essential. As one blower cannot run forever, an alternate blower of same capacity is highly essential and installed. For this capacity

hatchery two-twin lobe, roots-type air blowers each with the output of 300 m^3 air per hour at a pressure of 3 kg/cm^2 are essential. This also has the water replacement capacity of 2000 mm vertically. These blowers are individually fitted with separate 5 HP electric motors and run alternately every six hours.

The compressed and blown air is taken to tanks by suitably reduced P.V.C. pipes and finally through diffusion stones. Free fresh airflow in to the blower room is ensured to avoid heating.

Water

Intake: Pump house is set close to sea to avoid suction loss. A 5 HP electric motor and a self-priming pump is used for se water pumping. This unit is in duplicate to overcome breakdown and is kept in a separate room. Seawater is pumped during morning hours at high tide peaks. Salinity of the seawater is checked before pumping is done. Raising high tide may sweep the intertidal waste and suspended solids along. so pumping during peak high tide is better. Pumping through shallow shore-bore inside the inner margin of low tide mark or further interior assures filtered water in majority of the sandy bottom intake points in sea. Water pumped initially for one or two minutes is not collected as it brings noncirculated dark-stored water of the suction line.

Water thus pumped is let into the 50 ton settling tank. When suspended solids either organic or inorganic are found more and anticipated settling time allowance is shorter, alum can be used for quick settling. There is no aeration grid in this tank. After assuring full settlement water is pumped to the adjacent 50 ton holding tank through a gravity sand filter by a 2 HP Motor and Pump. While pumping it is seen that the nonmetalic foot valve is at least 3 inches above the tank bottom to avoid suction of settled matter. This three inches water is drained out every day and the tank is flushed and sun- dried before next day's use. At least once in a week applying powder chlorine in high concentration disinfects the tank.

Sand filter

The gravity sand filter (2 x 1 x 1 m) is strategically built in between settling and holding tanks. It is kept on a raised platform to the extent that its bottom and holding tank's top are in equal level permitting gravity flow. The filter bed is made of

3 layers of filter materials totally occupying 75 cm height of the sand filter leaving only 25 cm free board for water holding. A 2" dia. outlet PVC pipe with a PVC ball valve is fitted at the bottom of the filter which can regulate the out flow and rate of filtering as one desires. Slow filtering assures efficient filtering particularly when trace suspension load is still there after settling. As water clarity is highly detrimental for larval culture, checks are frequently made on the filtered flowing water for water clarity.

The filter bed bottom (20 cm) is filled with 2" and 4" blue metal. Above this a synthetic net is spread all over the bed and the lateral free margins of the net is adhesived to the sidewalls. Above this, for 30 cm height, an admixture of ½" blue metal, coral pieces and activated carbon are spread in equal proportions. This ½" blue metal increases about 25 times its surface area more than itself as a single block. While the thousands of pores in a single coral piece and millions of pores in activated carbon increases the surface area many thousand fold. This increased surface area enables settlement and trapping of fine suspended matter and also houses nitrifying aerobic bacteria which mineralise the organic load in the water particularly when the flow of the water through the bed is slow and steady. Over this middle bed suitable netting is spread. The mesh does not allow the overlying sand particles in the top most layers to pass through. The top most layer is filled with very fine, 'wind blown' beach sand to a thickness of 25 cm. As the water is already settled clogging may not happen. This system is periodically flushed back (backward) to remove the inorganic sediments.

Disinfecting : The filtered water is stored in a 50 ton shallow holding tank for atleast half a day when full sunlight is available. The sunlight spectrum kills certain bacteria. If opted, chlorination can be done in this tank after estimating the strength of the chlorine and deciding the dose to kill bacterial load. A dose stronger than the 'sufficient to kill' is preferred as partially killed or denatured bacteria will be activated by sunlight and such bacteria will have more unknown harmful effect. This holding cum chlorination tank should be provided with air bubbling grid for uniformly spreading the chlorine and dechlorination subsequently. After chlorination air bubbling is stopped and water is kept still for at least 2 hours. And then

dechlorination is started by bubbling air through aeration grid through bigger holes of 2-3 mm vigorously. After 10 to 12 hours, water is checked for trace chlorine. Water should be completely free of chlorine. When there is an urgent need for chlorinated water before completely dechlorinated for use in the hatchery trace chlorine is estimated by 'Toluidine method' and equal amount of sodium thiosulphate is added. This instantly removes chlorine from water. When powder chlorine is used, after removing all the chlorine, water is allowed to settle, so the precipitates of sodium thiosulphate is settled down. In such situation water pumping is done by keeping the foot valve 2" above the bottom of the tank to avoid suction of chlorine and thiosulphate precipitates. Before pumping this water, the temperature of the dechlorinated water is checked and compared with that of the culture tank water to make sure the temperature difference is not more than 1° C. When the water is to be used for live feed culture (rotifer) or nursery the temperature difference can be more than 1° C and not more than 2° C. Temperature difference makes stress to the crab larvae as they are very delicate and become susceptible to disease. Chlorine precipitate clogs the gills and burns it and gills become reddish, and its function is hampered leading to mortality. When chlorine is added to water pH marginally reduces and adding sodium hydroxide in suitable dose rectifies this and pH is maintained between 7.5 and 8.2.

Seawater thus collected, treated and filtered is used for culture needs. Periodically the aeration system and water lines are disinfected. Whenever the filtering rate in the filter is considerably reduced or once in three months the filter bed is given a 'back wash' and cleaned.

A separate pipeline is set for freshwater also with a two ton overhead tank. Fresh water can also be used to disinfect culture tanks to an extent.

Other equipments

One 0.25 HP electric monobloc pumpset is used for pumping the phytoplankton to the larval rearing tanks. Two numbers of 300 l capacity refrigerators, a mixer grinder, 10 l capacity pressure cooker, Electric stove and a kitchen balance are required. For the regular monitoring of the hydrological parameters thermometer, pH meter (digital pocket type), salinometer *etc.* are used. In

the laboratory one electronic balance (0.001 accuracy), monocular compound microscope, chemicals and glassware are kept for various observations. Phytoplankton and zooplankton counting trays are used for the determination of feeding quantities. For the routine work in hatchery plastic items like basins, buckets, mugs are also essential. For pumping phytoplankton to the larval rearing tanks 50 mm and 75 mm polythene hoses are used. The another important item required are filter cloths of varying mesh sizes from 40μ - 500μ mesh size and filter bags of 5μ.

Hatchery operations

Collection of berried females

From the wild, healthy berried crabs of 130 mm and above in carapace width (preferably with dark coloured sponge/berry) are collected and kept in the broodstock holding tank, which is fitted with an *in situ* recirculating system. When crabs with yellow berry are collected, the duration of broodstock maintenance is more and when the berry become deep grey such spawners are transferred to the hatching tank.

Hatching tank

The hatching tank is filled with known volume of filtered seawater. Normally prophylactic treatment is given. Only one crab is introduced in a hatching tank, with aeration during the evening. The water quality parameters are same as that of broodstock holding tank; water temperature 27-30° C, salinity 30-35 ppt and pH 8.0-8.2. Disodium salt of EDTA is added to the water @ 0.1 gm per 100 litres of water. The tank is covered with a black cloth to avoid light and to prevent it from jumping out of the tank. Anticipating hatching during the same night and to avoid initial starvation of zoeae, mixed phytoplankton dominated with *Chaetoceros* (cell conc. @10000 no./ml) is provided in the hatching tank. Hatching generally takes place in late night or early morning hours. Immediately after hatching, the mother crab is removed from the hatching tank.

Counting of zoeae

Aeration is stopped in the hatching tank for few minutes, allowing unhatched eggs, egg capsules, dead and weak larvae to settle down and they are siphoned out. For estimating the number of active zoeae hatched, the tank water is thoroughly mixed by stirring and three 100 ml samples are taken by a glass beaker. The number

of zoeae in each sample is counted and average number in 100 ml is computed. The total number of zoeae is estimated by:

$$\text{Average number of zoeae in sample} \times \frac{\text{vol. of seawater in the hatching tank (l)}}{0.1}$$

Larval rearing

Filtered seawater is further filtered through a 5μ mesh filter bag and used for larval rearing. The temperature and salinity are as that of the hatching tank. The newly hatched active zoeae are stocked in the larval rearing tanks at a stocking density of 50,000 no/t. Stocking is normally done during morning hours. On Day-1 simultaneously with stocking mixed phytoplankton dominated by *Chaetoceros* in its exponential phase of growth is added in the LRT and the cell concentration in the LRT is maintained as 10000 cells/ml. For Day-2 also the same cell conc. is maintained. On Day-3, while the larvae is still in the Zoea-1 stage, in addition to the phytoplankton, rotifers (*Brachionus plicatilis* – average size 192.75 ± 13.78 μm) at the conc. of 5no./ml is provided. The larvae metamorphose to Zoea-II on Day-4, till such time and for Z- II there is no change in the feed and feeding schedule. Z- II takes 3-4 days to metamorphose into Z- III and during this period the rotifer conc. in the culture tank is increased to 10-15 no./ml. and maintained for another 3-4 days till the larvae develop into the Zoea-IV. From Z-IV stage onwards no phytoplankton is added further to the LRTs. For Z-IV, rotifer concentration is increased to 20 no./ml and live moina (*Moina macrura*) is introduced at a tank conc. of 3-5 no./ ml and maintained for 3-4 days till larvae metamorphose to megalopa. While all the zoeal stages are active swimmers and column living and photopositive in habits, megalopae are basically bottom living showing occasional swimming in the water column. Megalopae are fed with live *Moina* at a conc. of 5-10 no./ml and rotifers 5no./ml. Along with this inert feed of egg custard macerated to a particle size of 200-250μ is added at short intervals. This is to avoid the water pollution by the inert feed. As the megalopae are highly cannibalistic, and to minimise it, an additional substrata of sea grass preferably of *Cymodocea serrulata* is provided. It is observed that larvae 'cling on' to the foliages of the seagrass and browse. Megalopa stage lasts for 3-4 days and moults to baby crab-crab instar I. The crab stages are mainly confined to the bottom

of the tank. On finding 1 crab instar/ baby crab in the culture tank, live feed supply to the tank is stopped. Thereafter frozen *Moina* and egg custard (particle size 350μ) are supplied as feed. Baby crabs are transferred to the nursery tanks when majority of the megalopae metamorphose to crab instar-1 (Plate.20).

During the entire larval rearing period, every morning 30-40% of the culture tank water is exchanged. During the process tank bottom is cleaned, excess feed and dead larvae are removed using suitable filter after stopping the aeration. For all the zoeal stages vigorous aeration is given, while for megalopa stage it is marginally reduced. It is also observed, particularly when the water is not chlorinated though filtered, a resident population of copepods develop in the culture tank after 5-6 days and later zoeal stages and megalopae prey upon these copepods (average size 729.9 ± 114.6mm).

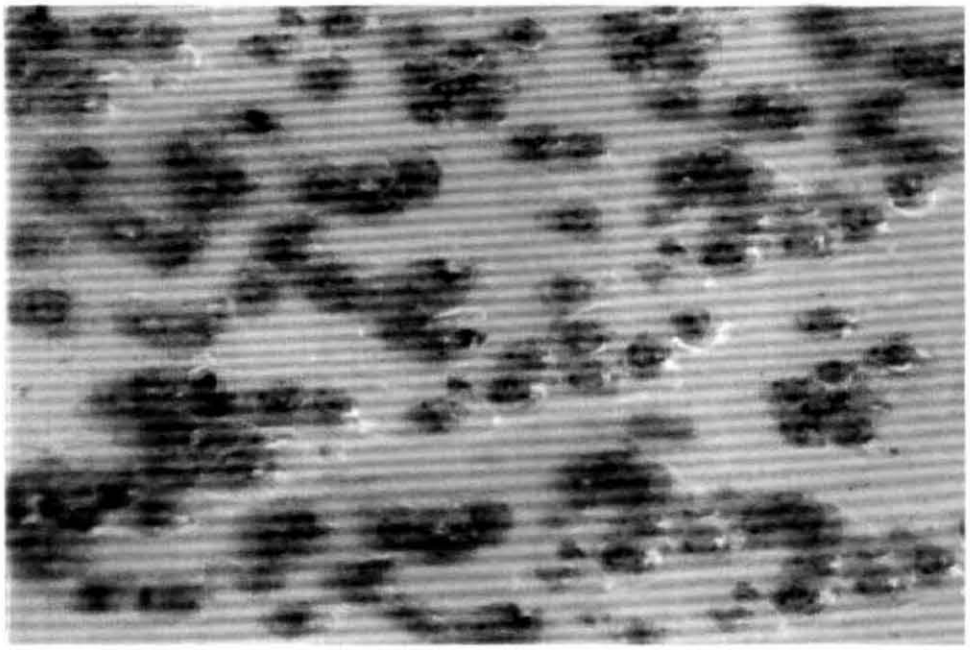
Daily at regular intervals larvae are examined under microscope to see whether the gut is full and the general condition of the larvae. It is generally observed that metamorphosis duration among zoeae and megalopae is not uniform, like that of shrimp. This results in finding late megalopae, one day old crab instar-1, two days old crab instar –1 and crab instar-2 in the same larval culture tank, though the offsprings belong to the same berry hatched at the same time. During the entire larval rearing period the hydrological parameters are in a range as follows.

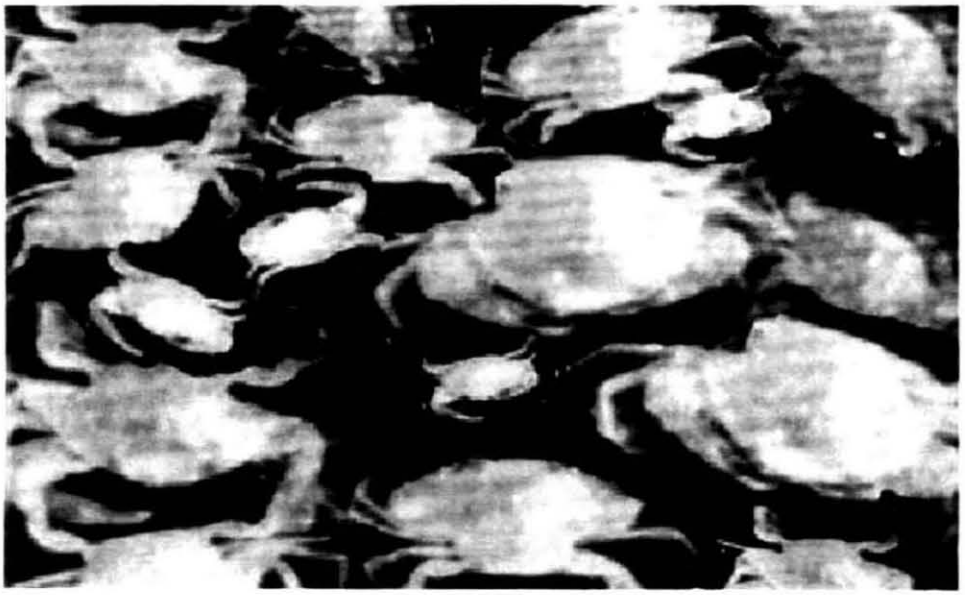
Parameter	**Range**
Salinity	29 - 35ppt
Temperature	26 - 32°C
PH	8.0 - 8.5
Dissolved oxygen	4 - 8 ml/l
Total ammonia	< 0.1 ppm
Nitrite	< 0.05 ppm

Harvesting

During the time of baby crab harvest, water in the larval rearing tank is reduced to $1/4^{th}$. Then the ball valve is opened gently and baby crabs are collected,

Plate 20





a. A group of first instars (baby crabs) *P.pelagicus*

b.two weeks old baby crabs

transferred to another tank of known volume of water. Based on this, the survival is estimated.

Nursery phase

The baby crabs are stocked in the 50t, rectangular, open outdoor tanks, at the rate of 400-500/ m^2. The depth of the water column is maintained at 80cm. For the first week, feeding rate and schedule are followed as in the case of first crab instar. In the second week of nursery phase, cooked clam meat (*Gafrarium timidum*) / small shrimp is given 20% of their body weight /day, in addition to the egg custard. 20% water exchange is given on every alternative days by removing water from the bottom layers. Care is taken to prevent the escape of crabs through the outlet by keeping proper mesh. The baby crabs attain an average size of 10mm carapace width at the end of the nursery phase and are ready to stock in a crab farm.

CONCLUSIONS

The demand for *P. pelagicus* as a delicacy has increased many fold during the recent past, in the fishery, its status as a 'by catch' is changing towards 'target fishing'. Since their stock in Indian seas is limited to very few pockets, the fishing pressure is adversely felt. At this juncture culture of this species and sea ranching are the two viable options left for augmenting and sustaining production.

This hardy species is already known to cohabit in shrimp and fish ponds with out affecting its production and stock in any manner. Frequent failures in shrimp farming has prompted the farmers to diversify and look for suitable alternate culture species. Among the edible crabs in India it is only mud crab and this 'blue swimmer crab' are candidate species as on today. In this direction, to develop a small scale hatchery for *P. pelagicus* various larval rearing experiments and trials were carried out to find out its food preference, habits and microniches. Having drawn conclusions from the study, the present hatchery is designed. This design is not of very much location specific, and can be functional throughout the year with inbuilt system to dry the tanks in successive batches. The under-roof and open nurseries guarantee 'sturdy seed' production to increase the survival in the not so hygienic ponds.

The differential growth, asynchronous moulting and difficulty in 'exuviae extrusion' generally make larval rearing difficult. Cannibalism among megalopae and baby crabs and totally different microniches for megalopae also make the seed production not so easy compared to that of shrimps. However, there is scope for further upgradation and modernisation of hatchery and growout systems in area of resource specific locations, together with adoption of location/ region specific management programme to sustain their production from the wild.

SUMMARY

SUMMARY

Present study is an attempt to standardise a technology for adoption in hatchery for mass seed production of *Portunus pelagicus* with a view to overcome the shortage of crab juveniles from the wild for farming and also whenever necessary, to replenish the depleting stock of the wild by sea ranching, which would help a sustainable fishery of this crab. Apart from hatchery production of *P. pelagicus*, its fishery, biology, larval rearing, growth and maturation are studied in detail.

After a preliminary survey of crab fishery in Palk Bay and Gulf of Mannar (where regular fishery of *P. pelagicus* exists throughout the year), four important landing centres *viz.* Mandapam-Palk Bay, Mandapam-Gulf of Mannar, Devipattinam (Palk Bay) and Thoppukkadu (Gulf of Mannar) were selected for the study. Each centre was visited every fortnight and detailed sampling carried out. Larval development studies and mass seed production of the *P. pelagicus* were conducted in the hatchery at the Mandapam Regional Centre of CMFRI at Mandapam Camp, Tamil Nadu. The study was carried out during the period 1995-98. The salient findings of the present study are given below.

At Mandapam-Palk Bay and Mandapam-Gulf of Mannar *P. pelagicus* is landed by shrimp trawlers as a by-catch. At Palk Bay side fishery is an year round process, whereas at Gulf of Mannar fishing activities are restricted to a season, October to March. At Devipattinam and Thoppukkadu crab fishing is exclusively by a traditional gill net known as *nanduvalai*, a crab net.

During the study period, it was observed that at Mandapam (Palk Bay) the total estimated catch was 502.38 t with an average CPUE and CPH of 4.2 kg and 0.324 kg respectively. At Gulf of Mannar- Mandapam area, the total landings for the same period was 30.68 t with a CPUE of 1.23 kg. At Devipattinam the total estimated catch for three years was 108.17 t with a CPUE of 13.3 kg and CPH 4.4 kg. At

Thoppukkadu, the total estimated catch for the three year period was 17.20 t and CPUE and CPH were 2.01 kg and 0.67 kg respectively.

For stock assessment, data pertaining to trawl fishery which is the major single gear in the exploitation of crabs was used. In males, the $L\infty$ values estimated using different methods ranged between 191.9 and 223.0 mm while in females it was between 190.0 and 196.9 mm. The total mortality coefficient (Z) was estimated sex wise from the size frequency data by length converted catch curve method (Beverton and Holt, 1964). Similarly, the natural mortality coefficient (M) was estimated by the Rikhter and Efanov method (1976) and Pauly's method (1980). The fishing mortality coefficient (F) was estimated using the formula Z-M. The values of Z, M and F were 4.54, 2.09 and 2.45 for males and 3.03, 1.46 and 1.57 for females.

In *Portunus pelagicus*, sex can be easily distinguished from the carapace colour pattern with males appearing more attractive than females. The carapace of the male crab is brilliantly coloured with irregular white patches and tips of chelate and walking legs bright blue as indicated by its name 'blue swimmer crab'. While, female crabs are dull brown with small irregular white patches on the carapace and tips of chelate and walking legs in dark brown colour.

The allometric relation between the sets of morphometric characters studied suggested in most of the cases as positive and highly significant. Carapace Width (CW) and Total Weight (TW) relationship has shown that females are slightly heavier than males till 120-125 mm carapace width and thereafter males are heavier than females. The exponential values (b) for the carapace width-weight relationship in males and females (3.607 and 3.293 respectively) have shown that there is marked variation from the isometric pattern of growth.

Sex ratio at Mandapam (both centres) shows that females outnumbered the males and the male: female ratio was 0.72: 1 with variations during different months of the year and period of study. At Gulf of Mannar side it was 0.9: 1 with similar variations as

that of Palk Bay. Devipattinam and Thoppukadu showed preponderance of males with the sex ratio as 1.13 : 1 and 1.26 : 1 respectively.

The structure of male and female reproductive systems of *P. pelagicus* closely resembles that of the other portunid crabs. Gross examination of gonads indicated that male *P. pelagicus* attained sexual maturity when they reach a size of above 80 mm carapace width. The smallest size of mature male obtained in the present study was 82 mm carapace width. The percentage of maturity increased with size, reaching 100% in 130 mm and above. Out of the crabs examined 15.03% were immature, 22.9% maturing and 62.1% mature. In females the smallest size recorded during the study was 88 mm (CW). The minimum size of berried female encountered during the study ranged from 105/ 80 to113/90 (mm/g) in all the centres.

Among the 5768 nos. of *P. pelagicus* sampled during the observation period in all the four centres, 48.4% were males and the rest were females. In females 5.4 % of crabs were infested with parasite (*Sacculina*) and the percentage of attack was more at Devipattinam.

The number of eggs present in the sponge / berry in *P. pelagicus* ranged between 0.06 x 10^6 and 1.98 x 10^6. Among the various relationships (CW-Fecundity; CW- Egg mass Wt.; TW-Fecundity; TW- Egg mass Wt.) studied, CW and fecundity were found to be better indices for the estimation of the reproductive potential rather than the weight of the crab.

The diet of *P. pelagicus* mainly consists of crustceans, molluscs, fishes, large quantity of unidentifiable matter and debris. The 'frequency of occurrence' method showed that miscellaneous items (83.09%) and debris (79.59%) were present in majority of the cases followed by crustaceans (78.43%), molluscs (59.48%) and fishes (56.27%). Whereas, by 'Points method', crustaceans was the dominant food item followed by molluscs and fishes.

The newly hatched zoeae were active swimmers and highly photopositive. They passed through four zoeal stages and one megalopa stage before they moult into the first crab stage. Each stage had taken 3-4 days duration. The larvae were fed with *Chaetoceros*, rotifer, *Artemia*, *Moina*, egg custard. Maximum survival recorded was 20% from Z-1 to first crab.

Growth of male and female crabs was studied in the laboratory from the first instar onwards. The males have grown from an initial average carapace width of 2.38 ± 0.18 mm to 159.86 ± 3.52 mm; ie from first instar to sixteenth instar within a mean period of 272 days and further reared to a maximum of 455 days. The average total weight gain was 275.00 ± 25.41 g from an initial weight of 0.008 g. Females have grown from an initial average carapace width of 2.43 ± 0.34 to 154.31 ± 2.73 mm, reached sixteenth instar within a mean period of 332 days. The average weight gain during the same period was 210.33± 18.39 g from an initial weight of 0.006 g.

The onset of maturity showed drastic change in the length of chelae in males on their 12^{th} moult coinciding with maturation. The total increment was 24.23 mm from the previous moult registering 97.51% increase in chelar propodus length. In females, abdominal width increment was 9.81 mm (39.13%) during the maturation moult *i.e.* 14^{th} moult. So it is assumed that in *P. pelagicus* males, maturity is attained by 12^{th} moult and in females by 14^{th} moult.

In males, the weight increment was steadily increasing after each moulting. Maximum percentage of weight increment was in their 7^{th} to 8^{th} moult (263.88%) and minimum during 4^{th} to 5^{th} moult (21.95%). In females too, the weight increment was in an increasing order and the maximum and minimum percentage of increase was recorded during 7^{th} to 8^{th} moult (257.50%) and 4^{th} to 5^{th} moult (32.00%) respectively. In general, the percentage of growth decreased after maturity, particularly in female crabs.

In *P. pelagicus* copulation takes place when the female is soft and male is hard. The male crab carries the female underneath the male and is firmly held by the third and fourth walking legs. This pair formation usually starts 3-4 days before the females moult. Copulation occurs during night hours as soon as the female is moulted.

During the present study 24 spawnings were observed in the laboratory. The spawning occurred within a period of 15-26 days after the copulatory moults during night hours. The mean duration was 18.6 ± 4.83 days. Fecundity ranged between 60,000 and 13,25,000 with an average number of 5,44,782. Total incubation days varied between 8 and 10, with a mean of 9.3 ± 0.78 days. The newly spawned eggs/berry was bright yellow and the colour changed to dull yellow as it reached mid of incubation and finally to dark grey in colour.

Data on growth in the laboratory was analysed for VBGF using three different methods viz. Gulland and Holt, Munro's and Fabens. The L_∞ values ranged between 204.1 and 219.8 mm in males; and 188.6 and 211.8 mm in females. The growth coefficient (K) varied between 1.8 - 1.9 and 1.62 - 1.7 in males and females respectively.

The design and layout for a small scale hatchery is given in the last chapter. The built area of hatchery is 40 x 36 m and roofed area is 28.5 x 15.5. The centre of the hatchery occupies larval rearing tanks of 5t capacity (10 nos.) and along the sides larval rearing tanks of 1t capacity (20 nos.) placed on a 30cm raised platform. The hatchery is designed in such a way that both sides of the hatchery slopping towards the central drainage. There are provisions for laboratory, office, store room and toilet inside the hatchery. Nursery tanks of 50t capacity (10 nos.) also placed on either side of the main hatchery building . The pump house and air blower room, generator room, sea water holding/ storage tanks etc. are designed, between sea front and hatchery.

The design capacity of the hatchery is 5 million per year (10 runs/ year) with a 20% survival from zoea to crab stage. Live feed required for the larvae are mixed phytoplankton, *Chlorella*, rotifer and moina are produced in the hatchery.

Since it is the first attempt on commercial seed production of *P. pelagicus* it is concluded that the results of the present research work would definitely be beneficial to researchers, planners and aquaculturists in India and abroad.

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